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Handbook on Timber Engineering

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

SP : 33-1986

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FOREWORD

Users of various civil engineering codes have been feeling the need for explanatory handbooks and other compilations based on Indian Standards. The need has been further emphasized in view of the publication of the National Building Code of India in 1970 and its implementation. The Expert Group set up in 1972 by the Department of Science and Technology, Government of India, carried out in-depth studies in various areas of civil engineering and construction practices. During the preparation of the Fifth Five-Year Plan in 1975, the Group was assigned the task of producing a Science and Technology plan for research, development and extension work in the sector of housing and construction technology. One of the items of this plan was the production of design handbooks, explanatory handbooks and design aids based on the National Building Code and various Indian Standards and other activities in the promotion of the National Building Code. The Expert Group gave high priority to this item and on the recommendation of the Department of Science and Technology, the Planning Commission approved the following two projects which were assigned to the Indian Standards Institution:

a) Development programme on code implementation for building and civil engineering construction, and

b) Typification for industrial buildings.

A Special Committee for Implementation of Science and Technology Projects (SCIP) consisting of experts connected with different aspects was set up in 1974 to advise the ISI Directorate General in identification and guiding the development of the work. Under the first programme, the Committee has so far identified subjects for several explanatory handbooks/compilations covering appropriate Indian Standards/Codes/Specifications which include the following:

Design Aids for Reinforced Concrete to IS : 456-1978 (SP : 16-1980)
Explanatory Handbook on Masonry Code (SP : 20-1981)
Explanatory Handbook on Codes of Earthquake Engineering (IS : 1893-1975 and IS : 4326-1976) (SP : 22-1982)
Explanatory Handbook on Indian Standard Code of Practice for Plain and Reinforced Concrete (IS : 456-1978) (SP : 24-1983)
Handbook on Concrete Mixes (SP : 23-1982)
Handbook on Causes and Prevention of Cracks in Buildings (SP : 25-1984)
Summaries of Indian Standards for Building Materials (SP : 21-1982)
Handbook on Concrete Reinforcement and Detailing (SP : 34-1986)
Functional Requirements of Buildings
Functional Requirements of Industrial Buildings (SP : 32-1986)
Foundation of Buildings
Steel Code (IS : 800)
Building Construction Practices
Water Supply and Drainage with Special Emphasis on Plumbing (SP : 35-1987)
Bulk Storage Structures in Steel
Formwork
Fire Safety
Construction Safety Practices
Tall Buildings
Inspection of Different Items of Building Work
Loading Code
Prefabrication

This Handbook, formulated under this project, provides information on the factors that influence timber engineering design and discusses them in detail. It provides explanatory review of Indian Standards on timber engineering and Part VI/Section 3 Wood of National Building Code of India 1983. The relevant literature available on the subject has been considered while preparing the Handbook. The scope of the Handbook is, however, restricted to the use of solid timber and does not cover wood products, such as plywood, laminated material and sandwich constructions.

Wherever the symbol 'NBC' is used, it refers to Part VI/Section 3 Wood of the National Building Code of India 1983. Other important features of the Handbook have been highlighted in the introduction.

The Handbook, it is hoped, will be useful to designers of timber structures, field engineers and also laboratories engaged in design, research and testing of structural timber.

The Handbook is based on the first draft prepared by Shri A.C. Shekar, Retired Director, Forest Products Research, Forest Research Institute and Colleges, Dehra Dun. The draft was circulated for review to Inspector General of Forests, New Delhi; Forest Research Laboratory, Bangalore; Dr A.N. Nayer, New Delhi; Directorate General of Technical Development, New Delhi; Western India Plywood Ltd, Cannanore; Indian Plywood Manufacturing Co Pvt Ltd, Dandeli; Indian Plywood Industries Research Institute, Bangalore; Forest Research Institute and Colleges, Dehra Dun; Central Public Works Department, New Delhi; and Public Works Department (J&K), Srinagar, and views received have been taken into consideration while finalizing the Handbook.

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1. INTRODUCTION

1.1 Wood is one of the earliest materials used by mankind for building purposes and has continued to attract attention in one form or other inspite of many competitive building materials and their use under highly developed technological considerations. Wood is a biological material from renewable resources, and extensively used in structural designs and other engineering fields. However, timber engineering developments are only of recent origin in India. It is only in the past thirty years, new design and test methods have been developed, a few types of properly designed wood construction have come up, and wood has been recognized as an important building material (*see* National Building Code of India 1983).

1.2 The present use of wood and other cellulosic materials, from forests, such as bamboo, thatch, reeds for residential and commercial types of buildings varies from about 10 percent of the total cost in cities and urban areas, to even 100 percent in hills and remote villages where modern architecture linked with economic improvements, has not yet made much impact. In some of the developed countries of the west, use of timber has brought out several new types of architectural designs also, and wooden structures are reported to have stood the test of time for several years. Even in this country examples exist in villages, old temples, some old palaces, etc, where wood has stood the test of time under continued use for even more than 200 years.

1.3 Several international and national seminars held between 1955 and 1975 recognized that one of the prime factors in not using wood extensively as an engineering materials is due to the scant attention received in the present-day training programmes of architects and engineers. These seminars, coupled with several R & D activities in India, have now scientifically and technically brought out that wood can be used economically in several ways, such as beams, rafters, purlins, trusses, columns, doors, windows, frames and shutters. It has also been used for flooring, panelling, ceilings, roofings and partitions. It has been considered as an excellent and attractive material for interior decoration and furniture. Laminated and improved woods have enhanced utilization of low grade quality even for high class architecture, both for stress-bearing as well as non-stress-bearing components. Improved processing techniques have increased durability characteristics and effected greater economy. On the basis of these experiences more than 30 Indian standards have been brought out which are useful in the field of timber engineering. Some of the essential aspects of designs, etc, have already been incorporated in the National Building Code.

1.4 In view of the above it has been considered necessary to bring out the present Handbook to consolidate and update the information available in this field and which is not fully covered in NBC and several Indian standards. It also provides a handy document to engineers, architects and builders, and other technologists dealing in wood constructions. The material contained is generally restricted to experiences in India and on Indian species only, but attention has also been drawn wherever necessary to some cases of design trends in other countries which may prove useful for future development in this country also. For obvious reasons of insufficient data and experience in this country, this Handbook cannot be considered as exhaustive document to cover all types of wood structures that have been and can be further developed with wood and wood products in this country. It is hoped that with the rapid developments coming up the future revisions of this Handbook will appropriately take care of the variety of needs in this country keeping in view the limitation of the many species of wood available in this part of the world.

1.5 No separate section for terminology has been introduced in this Handbook as IS : 707-1970 contains exhaustive list and many technical words used here are covered in the same. Some of the special terms are either covered in the relevent standards quoted in different places or explained in the text itself where they occurred.

1.6 A list of Indian Standards useful for timber engineering is given in Appendix A.

2. TIMBER FOR STRUCTURAL PURPOSES

2.1 General

2.1.1 When any material is used for engineering purposes, it will be helpful for rational utilization of the same, if the basic concepts and properties of the material are well understood. Wood is a material of biological origin and is considered by a biologist as a congregation of a number of biological cells which have some definete assigned functions during the growth of a tree. The construction of these cells, their wall thicknesses, binding to each other, distribution and alignment in a piece of wood, all go to determine the behaviour of the material in use. They also serve as a guidance for identification of timber as to which species it belongs. The chemist, considers wood as a bundle of chains of cellulose molecules coupled with hemicellulose, lignin and a few other extractive chemicals, all of which render the necessary properties to the same as a raw material for many chemical industries. In the concepts developed by a physicist, wood is an orthotropic material with different and widely varying mechanical and physical properties in the three principal directions of a piece of wood, that is, one along the direction of fibres, and the other two perpendicular to the same known as longitudinal, radial, and tangential directions respectively (*see* Fig. 1). Like some other materials, it is also elasto-plastic even at room temperatures, that is, it shows time-dependant strains under some minimum stresses known as 'limits-of-plastic flow'.

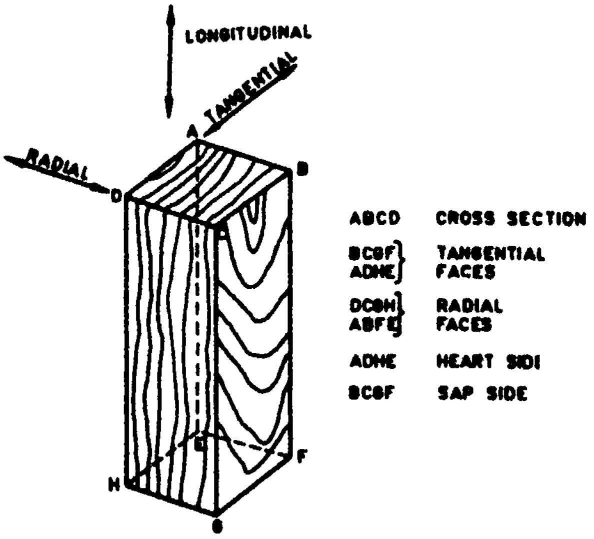


FIG. 1 PRINCIPAL DIRECTIONS AND SURFACES OF SYMMETRY IN TIMBER

2.1.2 Thus its properties exhibit variations not only due to different species of wood, different trees of same species, different localities and conditions of growth, but also due to methods of test and conditions of materials at test. Hence in the use of such a material with the required confidence for safety and wide acceptability, there in an absolute need of a high degree of standardization to obtain test data based on statistical and technological considerations, and there is a need for a strict code to ensure economy and safety. In the following sections all these aspects have been discussed mainly from the point of view of a structural engineer using timber.

2.1.3 During the last fifty years, the Forest Research Institute, Dehra Dun, had systematically established identification characteristics of different species of woods grown in India, evaluated several of their important properties and established suitability of various species for different industrial and engineering purposes. From considertion of their availability and other important properties, like mechanical and physical properties, durability, refractoriness to drying, workability, glueability, etc, out of nearly 300 commercial species tested so far, only about 85 have been identified as useful for engineering structures (*see* NBC 1983). However recent analysis of strength data of more species have indicated possibilities of utilizing many other species for structural purposes under different conditions. These aspects also have been discussed in the following sections.

2.2 Growth and Development of Timber Engineering in India

2.2.1 Timber has been used in India structurally as well as non-structurally from times immemorial for various types of house building purposes. In the early days there was no scientific data for proper designs, and consequently many of the early attempts on timber structures have been attributed only to hit and try methods, craftsman techniques, using only durable species, particularly teak. Sometimes protection to some non-durable woods against decay and insects was given only by surface coating of oils, paints, etc, which were not fully effective under all types of circumstances. Occassionally, instances can also be observed when protection was given to wood by simple smoking and charring methods. However, by about 1920, mechanical tests on different species under somewhat standardized conditions began at the Forest Research Institute, Dehra Dun. In due course of time, by about 1935, these results yielded quite reliable data for developing working stresses and designing of simple beams, columns and small trusses. Tests were also started on structural sizes of timber as early as 1936 and about the same period a note was also brought out by S. Kamesam on protectional methods for structural timbers against fire, termites, borers and fungi. Subsequently conventional trusses of spans ranging from 3 to 10 m have begun to be designed and were erected in different parts of the country by different constructional agencies using ordinary bolts and metal bindings. In some of the army specifications, some of the strong and durable woods were recommended based on standardized designs of earlier British defence specifications. These were largely used for temporary constructions during World War II. However, with the creation of a new Timber Engineering Branch in 1950 at the Forest Research Institute, Dehra Dun, small dimensioned stock came into use for structures, using nails and bolts, etc. Dowel discs and other connectors were developed which were subsequently utilized in the various types of light and heavy constructions. The Indian species by this time have been classified according to their strength, durability, refractiveness to drying, and other characteristics. On the basis of these classifications, and further studies on effects of defects, developments have taken place in grading structural timber not only according to their strength and durability but also according to their availability and possible end uses and whether for temporary or for permanent constructions. Also with the increasing costs, and shortage of naturally durable timbers like teak, sal, deodar, etc; and with developments in the processing techniques, the secondary species which were originally considered unsuitable, were used under proper treated conditions with the same confidence as conventional timbers. The design aspects of timber structures had been codified and incorporated in the National Building Code and several Indian standards have come up for use of timber in building industry. Indian standards for special types of constructions also have come up. Considerable amount of published literature is now available on research and developments that took place in the last three decades in India. More important Indian specifications and technical literature are given in Appendices A and B. With more developments in wood technology, particularly plywood and laminated materials, it is hoped more timbers and new designs of timber products will come into use for structures. The wide publicity and extensive demonstration structures are required in order to develop greater confidence, and introduce timber designs in several regional and institutional construction codes.

2.3 Timber Resources of India for Structural Purposes

2.3.1 Indian has about 75.3 million hectares or about 24 percent of land area under forests, which are unevenly distributed. All the forests are not fully inventoried for the different species though currently some efforts are going on for systematic survey of forest resources in the different regions. Much of the currently available information in the National Building Code and in many of the Indian Standards, as reported in the Handbook is based on the data supplied by the local forest departments on the basis of their preliminary surveys only.

2.3.2 These forests contain a variety of plant life. Of these, woody plants alone constitute more than five hundred species distributed in different parts of the country. Commercial wood is known as timber. All commercially utilizable wood, for example, timber, comes from two main types of trees known as 'gymnosperms' and 'angiosperms'. Trees of the former type are also known as 'coniferous trees' which have needle type leaves. Among the trees of the latter type, there are two further divisions: (a) dicotyledons and (b) monocotyledons, the names suggesting that their seeds contain two lobes or single lobe. Dicotyledons are also refered to as 'broad-leaved' trees, and the monocotyledons produce meterial which have bundled type of fibres, like palmyrah and bamboos, etc, which are used generally in the round or circular sections as such for obtaining their full strength. Timber from coniferous trees is sometimes referred to as 'softwood' and that from the broad leaved trees is referred to as 'hardwood' though the nature of the wood from the respective trees has nothing to do with softness or hardness as the terms are commonly understood. There are many hardwoods which are soft in nature like cotton wood (semul) or balsa. Similarly there are quite a number of softwoods which are fairly hard like 'fir', 'deodar', etc. Hence the use of the terms 'softwoods' and 'hardwoods' are being discouraged in Indian standards for identifying the origin of the wood, and the words 'coniferous' and 'non-coniferous' or 'broad-leaved' for trees and woods are being increasingly used in many publications.

2.3.3 All the species are known by their botanical names (as *Tectona grandis*) consisting of two parts; the first is the generic name, indicating the genera from which the woody material has come, and is always written beginning with a capital letter. The second part indicates the name of the particular species, and is written beginning with a small letter. It is always possible that under the same genera there can be two or more species with distinct botanical identity (for example, *Terminalia tomentosa, Terminalia arjuna*, etc). However commercially, the woods are known by 'trade' names and it is possible the same trade name is used for more than one species but belonging to the same genera (for example, Gurjan and several *dipterocarpus* species). A list of botanical names and corresponding trade names of all species along with abbreviations used for the species are given in IS : 1150-1976. In most of the Indian standards, both the botanical and the trade names are usually given. In the recent years, there have been some changes in botanical names in the light of fresh knoweledge about the botanical characteristics of the trees from which wood is obtained, and in accordance with international rules for naming the species. For this purpose the botanical names are sometimes followed by names of the authors who so named the species, such as *Mangifera indica* Linn and *Albizzia procera* Benth but this is not a regular practice in all technical literature. IS : 399-1963 gives botanical names and trade names of commercial timbers. Some of the botanical names have subsequently been changed and are reflected in NBC 1983. However, the trade names remain generally permanent as they came to be used popularly and widely both in commercial markets and technical literature. These timbers are also known by their 'local names' in regional markets.

2.3.4 The total recorded production of wood in the country is roughly estimated as 25 million m^3 per annum of which approximately 10 million m^3 is currently demanded by various industries including saw mills and construction industry. Of this, one can safely assume that approximately 2.5 million m^3 is now utilized in rural and urban houses and nearly 0.5 million m^3 for non-residential construction, and the balance of timber is used for other industries, such as plywood, railways, furniture, agriculture and pulp factories. It is, however, estimated that about 30 percent of the building materials is in the form of timber required for construction industry. On this basis, the current demand for timber for construction is expected to be of the order of about 6 million m^3

and this will increase more rapidly in the future. Although there are trends of increasing forest productivity to meet the demands of various industries and building constructions, the gap between availability and demand in future is still expected to increase and hence there is a need of greater economy and rational utilization of timber by developing new techniques in structural applications of timber. A number of other suggestions such as developing improved products of wood for structural purposes, utilizing more species and the odd sizes of trees hitherto considered not usable, raising fast growing species in forests, obtaining quick rotations in felling the trees, etc, are also under active consideration of the concerned authorities.

2.3.5 As known by the data suplied by various forest departments and the Forest Research Institute, nearly about 85 species have been indentified in the National Building Code as useful for structural purposese; and their primary characteristics, such as weight, availability, durability, refractoriness and treatability are given therein. Recent analysis of strength data of more species indicate the possibility of using some more species. These have been indicated in Appendix H along with other properties.

2.3.6 According to IS : 3629-1966 all the structural species are classified into three groups—'super', 'standard' and 'ordinary'—based on their modulus of elasticity for green timber as obtained under standard tests and also flexure stress in bending as obtained under working stresses (*see* **2.3**). But NBC classifies these into groups A, B and C based on 'modulus of elasticity' and gives permissible stress in bending, tension and flexural. However, as structural engineering design considerations of use of timber are based on permissible stresses obtained from standard tests, for all reactions like bending, compression and shear, these are also given in Table 1 for the three recognized groups along with standard specific gravity on which all properties generally depend, and which generally serves as a ready guidance for selection (*see* Sl No. 26 of Appendix B). According to a system of grouping several strength factors (*see also* **3.1.4**) and also expressing composite strength figures compared to teak as 100 the limiting composite strength figure as used in IS : 399-1963 is also given in the same table for the three groups. Earlier edition of IS : 833-1977 also suggests that permissible stress in bending of standard grade timber, under use in inside locations, as additional limiting factor for structural grouping. These and other corresponding permissible stresses are also indicated in the same table for comparison. Although, as mentioned in NBC, modulus of elasticity alone may be generally sufficient for classification of any species under different groups, the other criteria mentioned above also serve as a check and would be helpful to place any species in the respective groups with greater confidence. This has been necessary in some species, such as *Carallia lucida, Gluta travoncorica, Pinus lonifolia,* some *dipterocarpus* and *Terminalia* species, *Zanthoxylum rhetsa*, etc.

2.3.6.1 When the same species in different localities fall in different groups, the group of majority localities is taken, such as *Shorea robusta* (sal) of Assam, Bengal, Bihar and UP falls under Group A but that of MP falls under Group B. Similarly *Tectona grandis* (teak) of MP and Orissa falls under Group C but of Kerala, Maharashtra, UP and Bengal falls under Group B. Hence the above two species are taken in Group B. Similarly although *Stereospermum chelonoides* tested from Madras falls under Group B yet the same tested from West Bengal falls under Group C. Also other *Stereospermum* species like *Stereospermum swaveolens* from UP and *Stereospermum xylocarpum* from Madras fall under Group C. Hence all the *stereospermum* species have been shown under Group C only. As grouping of species for structural species is associated with safety and economy, in the long run, whenever there has been any doubt for appropriate grouping with regard to different strength characteristics and in relation to locality of growth, the safer side, that is, lower grouping has been adopted. It may be noted that different species of same genera may fall into different groups, such as *Calophyllum tomemtosum* in Group B, and *Callophyllum wightianum* in Group C. Similarly, *Terminalia arjuna, T. bellerica, T. bialata, T. chebula, T. manii, T. paniculata,* and *T. tomentosa* all fall under Group B, but *Terminalia myriocarpa*, and *T. procera* fall under Group C.

2.3.6.2 In a seminar on timber and timber products for building purposes held in Dehra Dun in 1977, a suggestion was made that there should be a fourth group, Group D also, for listing such timbers which are 'neither durable nor treatable', to be used for extremely temporary structures or other semi-structural purposes in service work. However, this has not been standardized as such, nor does it seem to stand logical permanent classification, as any timber can be used for such purposes, and technological developments in wood preservation are always directed towards improving durability and treatability of all such species.

2.3.6.3 When in any structure all the pieces of timber are from the same species, then it may be useful to employ the working stresses of the particular species as given in Appendix H. However, when a number of species are required to be used together, it is advantageous if all the species are of the same group and the working stresses of the particular group for a given condition as given in Table 2 would be justified for maximum efficiency and economy. The methods of deriving the working stresses are discussed in **3.3** in greater detail.

TABLE 1 PROPERTIES REQUIRED FOR DIFFERENT STRUCTURAL GROUPS

(*Clause* 2.3.6)

STRUCTURAL GROUP	TRADE TERMINOLOGY OF THE GROUP	MODULUS ELASTICITY, E N/mm^2	SPECIFIC GRAVITY*	BENDING, N/mm^2		COMPRESSION PARALLEL TO GRAIN, N/mm^2		COMPRESSION PERPENDICULAR TO GRAIN, N/mm^2		SHEAR, N/mm^2		COMPOSITE STRENGTH FIGURES AS IN IS : 399 COMPARED TO TEAK AS 100 (IS OF THE ORDER OF VALUE GIVEN BELOW)
				Ultimate Stress	Permissible Stress†	Ultimate Stress	Permissible Stress†	Ultimate Stress	Permissible Stress†	Ultimate Stress	Permissible Stress†	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
A	Super group	E > 12 600	$\rho \geqslant 0.73$	90	18.2	48	12.0	10.5	6.0	12.0	1.2	105
	Standard group	E > 9 800	$0.62 \leqslant \rho < 0.73$	60	12.3	28	7.0	4.4	2.5	9.8	0.9	80
C	Ordinary	E > 5 600	$\rho < 0.62$	42	8.4	26	6.4	3.5	2.0	6.0	0.6	50

*The specific gravity values are given only for general guidance and should not be used for classifying timber for which reference may be made to IS 883-1978

†Permissible stress is of standard grade of timber under use in inside locations (*see also* Table 2 and Appendix H).

TABLE 2 PERMISSIBLE STRESSES FOR GRADE 2 TIMBER

(*Clause* 2.3.6.3)

	LOCATION	PERMISSIBLE STRESSES, kgf/cm²		
		Group A (E = 126)	Group B (E=98 to 126)	Group C (E=56 to 98)
(1)	(2)	(3)	(4)	(5)
Bending and tension along grain	Inside locations	182	123	84
	Outside locations	152	102	70
	Wet locations	120	81	60
Shear	Horizontal, all locations*	12	9	6
	Along grain, all locations	17	13	9
Compression parallel to grain	Inside locations	120	70	64
	Outside locations	106	63	56
	Wet locations	88	58	46
Compression prependicular to grain	Inside locations	60	22	22
	Outside locations	46	18	17
	Wet locations	38	15	14

*The values of horizontal shears to be used only for beams. In all other cases shear along grain to be used.

2.3.7 For purposes of knowing the availability of the species India has been divided into five zones and the approximate quantity available in each zone is given in NBC 1983 and also in IS : 399-1963.

a) *North Zone* — Jammu and Kashmir, Punjab, Himachal Pradesh, Delhi, Uttar Pradesh and Rajasthan;

b) *East Zone* — Assam, Manipur, Tripura, West Bengal, Bihar, Orissa, Sikkim, Bhutan, Andamans, North East Frontier Agency and Nagaland;

c) *Centre Zone* — Madhya Pradesh, Vidharbha areas of Maharashtra and the North-East part of Andhra Pradesh (Godavari delta area);

d) *West Zone* — Maharashtra (except Vidharbha areas), Gujarat and North-West part of Karnataka;

e) *South Zone* — Tamil Nadu, Andhra Pradesh (except the Godavari delta area), Kerala and Karnataka (except North-West part).

However, it may be noted that the data on availability in different zone is only approximate and collected quite sometime ago. In the recent years the inter-zonal transport systems have been improved very much, and quite a lot of timber movement has been feasible economically. Hence, the total approximate quantity available in the country as a whole has been estimated and the principal areas of growth and availability along with trade names and other local names have been indicated in Appendix G. Species which are in heavy demand for other important industries have also been indicated accordingly.

2.3.8 Species of wood are to be chosen also according to their durability. The durability of species have been classified in IS : 399-1963 according to the behaviour of the heartwood sticks in 'grave-yard test', sometimes known as 'stake tests'. Test specimens of untreated heartwood of different species of size 60 × 5 × 5 cm are buried to half their length in the ground in different representative test centres in the country, containing different types of wood destroying agents. The average results are analyzed and the species are classified for durability as below:

High (that is, Class 1 of IS : 401-1982) (*H*) : Species, the test specimens of which indicate average life of 120 months or more, when tested as above.

Moderate (that is Class 2 of IS : 401-1982) (*M*) : Species, the test specimens of which indicate average life of less than 120 months, but 60 months or more when tested as above.

Low (that is, Class 3 of IS : 401-1982) (*L*) : Species, the test specimens of which indicate average life of less than 60 months, when tested as above.

It may be indicated here that the above is not the actual life for designed structures. The above is only a comparative classification of species for appropriate choice. Properly treated timbers give much longer life.

2.3.9 Species are classified also for 'treatability' to indicate approximately the degree of resistance offered by the heartwood of the species to penetration of the preservative under working pressure of 10.5 kg/cm^2 under conditions of treatment normally employed for creosote-crude oil mixture and also water soluble mixture (*see* **4.4**). There can be minor differences of treatability with different types of preservatives. Sapwood of all species is very easily treatable. Treatability classification of different species is as follows (*see also* IS : 401-1982):

a) Heartwood easily treatable;

b) Heartwood treatable but complete penertration of preservative is not always attained (IS : 401-1982 prescribes least dimension as more than 6 cm);

c) Heartwood only partially treatable;

d) Heartwood refractory to treatment; and

e) Heartwood very refractory to treatment, penetration of preservative being negligible even from side or end.

2.3.10 When species of wood are air-seasoned, as most of the constructional timbers of large cross-sectional areas would be, they are likely to crack and split. Under comparable normal conditions of seasoning, these are classified as of 'high', 'moderate', and 'low' refractoriness to air-seasoning, that is, to indicate likelihood of losses in air seasoning, or when exposed to normal weather in outside locations. This classification will help comparative selection of appropriate species in the different areas.

2.3.11 In the final selection of the species the NBC recognizes two choices as below depending on their combined durability and treatability. This will help engineers to adjust according to the required economy in constructions, particularly with reference to permanent or temporary, heavy or light constructions, and in selecting required treatment processes, etc. (*see* IS : 3629-1966).

2.3.11.1 *First choice* — The species can be any of the following:

a) Untreated heartwood of high durability (Class 1 of IS : 401-1982)

b) Treated heartwood of moderate (Class 2) and low (Class 3) durability, and of 'a' and 'b' treatability classes.

c) Heartwood of moderate durability (Class 2) and Class c treatability after appropriate pressure impregnation (*see* IS : 401-1982).

d) Sapwood of all classes of durability after thorough treatment with preservative.

2.3.11.2 *Second choice* — The species should be of heartwood of moderate durability and Class d treatability.

2.3.11.3 Although no specific mention is made in NBC and IS : 3629-1966 recognizing selection of species of Class 3 durability and Class c treatability for temporary structure when their life is not important.

2.3.12 Considering all the above, the timber resources for structural purposes in India demand a careful selection of species consistent with the required economy. In recent years, the cost of popular and durable species ranged from Rs. 500 to Rs. 1000 per cubic metre depending upon the sizes and grades. Some of the ornamental and decorative varieties to be used for wall panels even cost more, though plywood and other types of panels are gradually coming into vogue. The cost of sesoning has been around Rs. 75 per cubic metre and the preservative treatment on the average costed Rs. 150 per cubic metre. However, it may be remembered that the economy of timber utilization depends not only on the fluctuating costs of material and treatment in the markets, but also on the annual maintenance costs and the minimum longivity expected of any structure.

2.4 Selection and Identification of Structural Species

2.4.1 Wood identification is a highly specialized subject falling under the discipline 'Wood anatomy'. Some of the popular species in the various zones can be broadly guessed and identified by their 'gross features' such as grain, texture, colour, hardness and weight aided by the knowledge of locality of origin of the species. However, a pen-knife and a hand lens of 10 times magnification would be helpful for further confirmation of the timber by a closer study of the distribution of different types of cells. In order to have more accurate confirmation it would be essential to take their sections (of the order of microns in thickness) with the help of a microtome, and study the same under a microscope of higher magnification. Still the wood anatomists quite often feel that in some cases they would not be absolutely sure with regard to the species though they can confidently identify the genus. In extreme cases, the herbarium specimen, that is, the leaves, fruits and flowers of the tree, from which the wood has been obtained, will be required for establishing unquestionable identity. In general all the above tests, alongwith the herbarium specimen, are considered always necessary for absolute confirmation.

2.4.2 Identification of commercial species of India are usually done by what are called 'keys' for identification. There are two such system of keys in vogue. The first is called a 'dichotomous' key. A typical such key is given in Appendix C which includes only some of the timbers but it should be possible to construct such keys specifically for the structural timbers belonging to a particular group. The Forest Research Institute has published several keys for common commercial species available in various markets or for species used for specific purposes such as for motor lorry bodies. Some keys are constructed on the basis of features observed entirely by naked eye or a hand lens, and some are constructed on what can be observed under microscope. It is also possible to combine both. It is, however, not possible to prepare a key of this type for all available commercial timbers of the world or India. Also when such a dichotomous key is constructed for limited number of species against a background of common market or end use, additional species cannot be included without changing a large section of the same.

2.4.3 A second system of key for identification is through the help of marginally perforated printed pack of cards describing all features. IS : 4970-1973 describes this system of the key alongwith all aids required for the same. In this system the diagnostic features of each timber are recorded by V-punching out the margin of the perforations corresponding to the features of the timber printed on the card (*see* Fig 2). To identify a given timber, the whole pack of the printed cards are arranged together and a needle is inserted through the hole of the first feature observed. On shaking out all such cards of different species which have the same feature fall out. A second feature observed on the timber to be identified, is then selected and the above process of inserting a needle and shaking is repeated on the fallen cards so that some more cards fall out which have the same features. Thus one after another all features are taken up and ultimately only one card will fall out which has all the features observed, and this card gives the identity of timber under consideration. The advantages of this type of keys are: (a) one can

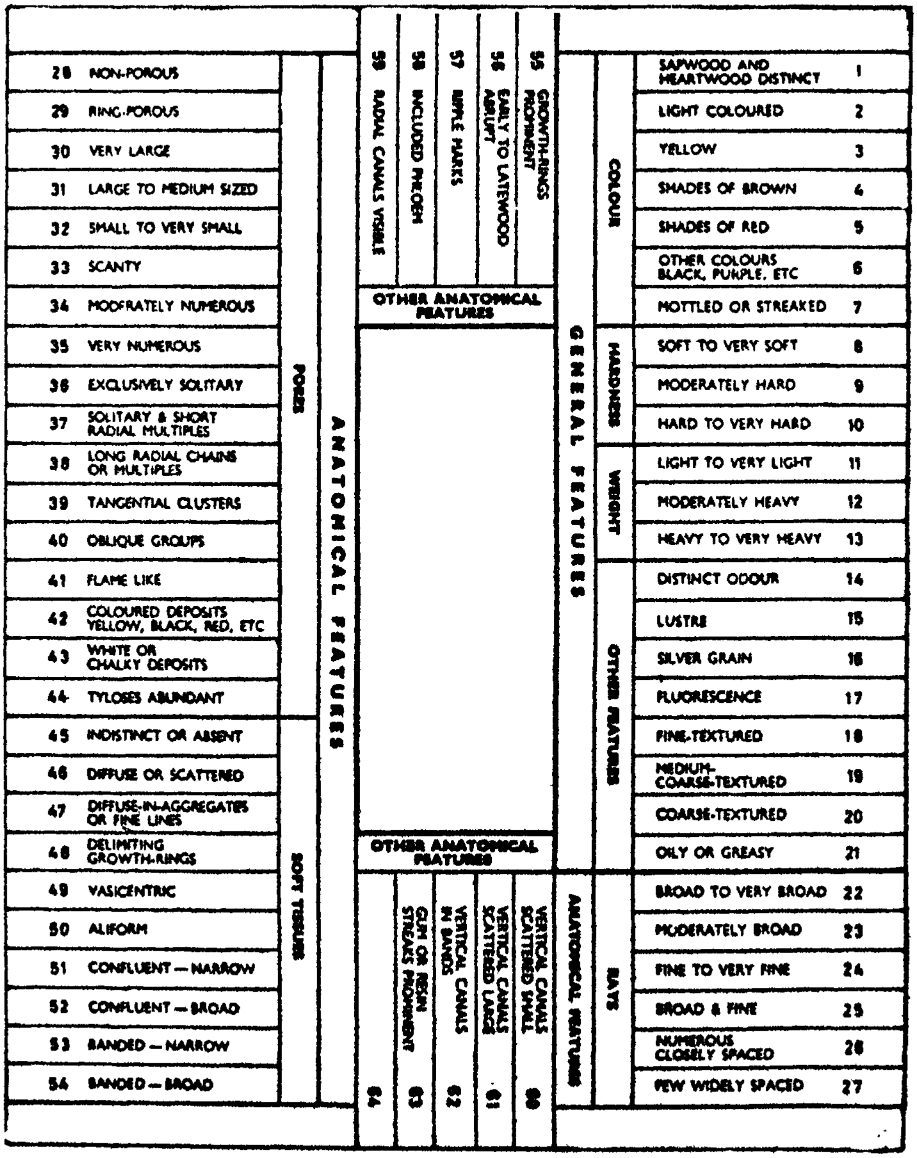


FIG. 2

start with any obvious or unusual feature, (b) the features can be used in any sequence and (c) any card can be prepared for any new timber species and added to the pack and selection is also based on negative characteristics, that is, cards of timbers, in which the selected features are not present remain on the needle itself when shaken.

2.4.4 Some people have tried to develop identification keys on the basis of chemical constituents of timber or mechanical and other physical properties of timber but these have not become popular as yet.

2.4.5 In all cases of identifying biological specimens, it is best in the end to establish identification by comparison with authentic specimen themselves and using all available keys. For this purpose purchasers and users of timber regularly are advised to keep in their custody a set of authentic specimen so certified by recognized laboratories such as the Forest Research Institute, Dehra Dun, and Forest Research Laboratory Bangalore and Peechi (Kerala), etc.

2.4.6 To be able to identify the different types of common features that are to be looked for on the different species in the process of their identification and selection, description of the same are given in **2.4.6.1** and **2.4.6.2**.

2.4.6.1 *Gross features*

a) *Bark* — The outer cover of a log, which many a time easily peels off on drying, is generally a rough surface. However, in some species like *Ficus* or *Eucalyptus* it is smooth. In *Shorea* species it shows fissures and cracks. In some species like *Melia* diamond shaped fissures are observed. The thickness of the bark and its general appearance is of some diagnostic value.

b) *Pith* – This is the soft core found near the centre of the log as seen at the end. When in dry condition, lot of radial cracks are observed. The colour is commonly some shade of brown or grey. It is rarely of any diagnostic value. The squarish ends with concave sides is sometimes considered typical of teak.

c) *Sapwood and heartwood* — When viewed on the cross-section of a log, two clear zones appear, the one comparatively lighter in shade and nearer the bark side is known as 'sapwood' and the inner zone near the pith, is known as 'heartwood'. These two zones contain cells with different functions in the growth of the tree. However, in a felled tree or a log stored in a depot, colour distinction is not always a true criteria for distinguishing them. In *Abies pindrow* (fir) and *Picea smithiana* (spruce) there is no colour distinction. Hardwoods like mango, semul, do not show the colour difference. In some species, for example, *Shorea robust*, the sapwood changes its colour from reddish brown near the heartwood region to nearly white nearer the bark. However, from anatomical point of view and also strength point of view there is no difference between sapwood and heartwood. The sapwood is a very easily treatable than heartwood, and so is always advantageous from the point of preservation and tretment of timber.

d) *Growth rings* — Most timbers show on the cross-section a number of concentric marks approximately annualar in shape, that is, circular around the pith and ultimately taking contour shape as of bark. Sometimes they are faint and sometimes they are prominently visible to the eye. The width of the ring consists of two parts, the wood formed in the early part of growing season known as 'earlywood' and (sometimes referred in literature as 'springwood') and the wood formed during later part of growth season known as 'latewood' (sometimes referred in literature as 'summerwood'). The two parts differ in texture, colour and general structure. The time interval between two such consecutive growth rings is usually a single alteration of growth season which is usually one year. Hence they are also often known as 'annual rings' and thus the number of rings provide a reliable idea of the age of the tree. Sometimes there can be 'false rings', and in some regions the growing season is not regularly annual. Sal, gurjan, jaman, and mango do not show any distinct annual or even seasonal growth rings because the growth is continuous and one season's growth merges into next season's growth. In conifers like chir, deodar, and in some broad leaved trees like mulberry, teak, toon, the rings are distinct and give a correct idea of the rate of growth. Fast growth indicates rings wider than 2.5 mm, and 8 rings or more per centimetre indicate slower growth. Width of rings has a significant effect on strength and sometimes they are of diagnostic value.

e) *Grain and texture* — These are somewhat loosely understood terms to indicate the direction, alignment and size of the cells as seen on the surface of piece of timber. These are also of some diagnostic value. The grain which is concerned with orientation of cells with reference to the axis of the tree is usually described 'straight', 'cross', 'spiral', 'interlocked', 'wavy', 'irregular', etc. The texture of wood is commonly described as 'coarse', 'fine', 'even' or 'uneven' to indicate the size, proportion and distribution of various wood elements. Sandalwood and haldu are fine textured woods; mango, hollock and kokko are coarse textured.

f) Other characteristics, such as colour, odour, hardness and weight as their names suggest, help in identification of very commonly known timbers but one should be very cautious in applying these to any unfamiliar wood.

2.4.6.2 *Minute structure of wood*

a) Depending upon the function expected of various types of cells during the growth of a tree, they are classified as vessels fibres, trachieds, parenchyme, etc. The size, proportion and arrangement of the various wood elements constitute the characteristic pattern, and celluler structure seen under a lens or microscope on the basis of which identity of wood is established. These are also responsible for making the specific species usable for specific end uses, and particularly building purposes where strength, nailability, glueability, insulating properties, paintability and treatability form important considerations.

b) *Pores or vessels* - They appear on the cross-section of broad-leaved trees as approximately a circular or oval openings or holes. Hence they are called pores. In coniferous woods they are not visible and so they are called 'non-porous'. The pores may by distributed in a ring form or diffused. In 'ring porous' woods, those of early wood are distinctly larger than those of late wood such as in teak, mulberry and toon. Hence a ring is clearly seen. In diffused porous wood, such as sal, haldu the pores are uniformly distributed. Sometimes there will be other types of groupings such as radial chains as in ebony and lambapatti, or in oblique grouping such as in poon. The pores may be minute in size as in *Gardenia* sp. or large as in semul and kokko. In the sapwood, pores may be empty but in heartwood they sometimes get filled with deposits and inclusions called 'tyloses' which are formed by ingrowth of adjoining cells as a part of heartwood formation. They appear as 'foam-like' structures. They are considered indicative of natural durability but reduce the easiness of seasoning and treatment.

c) *Fibres* - This is a somewhat misleading term. As commonly understood any thread-like or filament-like material of plant origin is a fibre. However, wood anatomists recognize this as vertically aligned, narrow elongated, thick walled, wood cell with tapering ends occuring only in hard woods and which impart mechanical strength to the tree in its growth, and make up the bulk of the wood by weight. They appear not individually but collectively in dark coloured patterns. Like vessels they are absent in conifers and the corresponding longitudinal elements in conifers are called tracheids which are described below. However in pulp technology the words 'long fibres' and 'short fibers' are used for the filament like materials in conifers and hardwoods respectively.

d) *Tracheids* — In conifers they have dual role of conducting the sap and also giving strength to the tree. They have pits on their walls like vessels, but have thick walls and tapered ends like fibres. The early wood have thinner walls, larger pits, larger lumen and the later wood contains thicker walls, less pits and smaller lumen, thus giving rise to prominent growth rings.

e) *Paranchyma cells* — Somewhat short, rectangular cells with thin walls, and pits designed for storage and conduction of food material during growth. Generally they are along the direction of growth of the tree, and hence known as longitudinal paranchyma. But sometimes they are formed among the cells running in radial direction and are correspondingly called radial paranchyma. The collective patterns of these cells are of important diagnostic value.

f) *Rays* — Horizontally oriented cells known as medullay rays running in radial direction appear as light coloured ribbons of various patterns giving distinct features. Broad, high rays are characteristic of oak, beech, etc. Fine inconspicuous rays are features of all conifers and some hardwoods like laurel, benteak and ebony.

g) *Ripple marks* — When viewed on the tangential surface, some wavy lines caused by rays running at right angles to the longitudinal direction are sometimes observed on some woods such as bijasal kanju and satinwood, and are very helpful in identification of timbers.

h) *Resin canals and gum ducts* — Intercellular canals, serving as repositories of waste products like resin and gums, either in vertical or in horizontal directions observed distinctly under a lens in some conifers like chir, kail, and in hardwoods like sal, vellavine and hopea. They are of varying shades of brown and varying sizes, which seems to be very good diagnostic feature as only a few timbers possess these.

2.4.7 After identification of any species of wood, another important factor which influences selection is identifying the common defects and assessing their influence on the stress-bearing capacity of the material. This is discussed in detail in 2.5 which deals with grading. Several Indian standard specifications have indicated the extent of permissibility of the defects for respective uses. Brief descriptions of some common defects, required to be identified for structural purposes are given below [*see* IS : 3364 (Parts 1 and 2)-1976]:

a) *Checks* — Identified by the separation of fibres along the grain observed on the longitudinal or end surfaces.

b) *Decay* — Also referred as 'rot' is commonly identified as brownish or greyish patches on the surfaces, and their condition is judged quantitatively by their surfaces. As these are caused by fungii which eat away the cell wall, the strength is affected unlike 'sapstain', in which the contents of cell and not cell wall are eaten. [*see* **3.2.4.5** and item (j) below].

c) *Flutes* — These appear on the surface of logs as longtitudinal depressions, deeper and wider at the butt-ends and gradually diminishing in depth and width as it reaches upwards.

d) *Grain orientation* — 'Spiral grain' is identified on the logs by the direction of surface grain, or fine hair splits between them as they spiral along the length either 'clockwise' or 'anticlockwise' as seen from the smaller end, that is, top of the log (also known as 'right handed' or 'left handed'). In cut timber, this appears as inclined in both radial and tangential surfaces and there can be some confusion as to the exact cause of any inclination of the grain to its longitudinal axis. Any grain appearing as generally not parallel to the longitudinal edges, are known by the general term 'cross grain' and includes different types such as 'diagonal grain' (caused due to material not sawn parallel to the axis of a straight log) 'inclined grain' and 'slanting grains' (caused due to natural orientation in the growing tree).

e) *Holes* — These are caused by insects, birds and mechanical injuries, and are classified in various specifications according to their diameters.

f) *In-bark* — Identified as patches of bark embedded in the wood partly or wholly.

g) *Knots* — These are left over portions of branches, separated from the main stem. They are classified according to their condition as 'live knots' (syn. intergrown knots, tight knots, sound knots) and dead knots (syn. unsound knots or decayed knots). Loose knots, encased knots, pith knots and hollow knots are all self-explanatory. They are classified according to their size and shape as circular, oral, spike, pin knots, small knots, and large knots which can also be recognized as their names imply.

h) *Reaction Wood* — In conifers, this abnormality in wood is found on the underside of branches and leaning trunks and known as 'compression wood'. It is characterized by heavily lignified trachieds rounded and distributed along the growth rings. They are denser and darker than surrounding tissues. In hardwoods this abnormal wood is found on the upper side of leaning trees and branches, and known as 'tension wood'. It is characterized by little or no lignification. The machine surfaces with such abnormality tend to be wooly. Converted timber containing reaction wood develops distortions due to high longitudinal shrinkage and reduces strength considerably.

j) *Rot* — *See* 'decay' above. The word 'dry rot' is commonly used to indicate wood that is crumbly, and not as is erroneously considered that it is grown on dry wood. Pathologists use this word to indicate action of some types of fungii such as *Merculius lacrymans* and similarly the word 'wet rot' as due to action of some fungii like *concophera cerebella*. As these attack only the cellulose without affecting lignin, the left over portion appears as brown and hence they are generally known as 'brown rot'. Certain fungii like *Polyporus hirsutus* can eat away all components of cell wall, so that the left out portions appear whitish and so popularly termed as 'white rot'. Study of action of different types of fungii, their identification and action on different species is a highly specialized subject of the pathologist, but for an engineer, particularly with reference to identify and evaluate the condition of the material by the nature of the attacked portion.

k) *Shakes and splits* — Shakes are seen only on the cross-section of the material as a partial or complete separation of wood tissues and are known as 'heart shakes' (extending in radial direction on the heart region of the cross-section) as 'cupshakes' (occuring between growth rings) and as 'starshakes' (emerging from the pith as a number of radial shakes and appearing as a star). 'Splits' are seen as separation of fibres both on the cross-section as well as on the longitudinal surface.

m) *Wane* — This appears as lack of wood material on edges or surfaces and indicates presence of original sapwood with or without bark.

n) *Warp* — Sometimes also referred as 'distortion', this is a general term for defects developed in seasoning or drying such as 'bow' (face concave or convex along the grain), 'cup' (face concave or convex across the grain), 'spring' (curvature in the longitudinal plane) and 'twist' (spiral distoration along the grain).

2.4.8 Some of the above defects can be appropriately measured and assessed [*see* IS : 3364 (Part 1 and 2)-1978] and their permissible limits form the subject of individual specifications. However in NBC, for the purpose of structural timbers, completely prohibited defects and permissible defects with limitations for different grades have been identified including permissible location of these defects. Loose grain, splits, compression wood in conifers, heartwood rot, sap rot, and warps are completely prohibitive defects. Wanes, knots, worm holes, pin holes, other than those due to live power-post beetles, checks, shakes, slope of grain are permitted to specified limits. It will be useful for any person using timber to be familiar with various other types of defects, whether natural or caused by subsequent processing techniques, or external agencies like fungii and insects by reference to standard literature and relevant specifications.

2.5 Grading Practices, Standards and Preferred Sizes

2.5.1 Grading a piece of timber for the required end use has been adopted in some form or other ever since timber was being utilized. Users of tool handles, builders of early structures, all knew mostly by trial and error methods, when and where to avoid defects like knots, splits and even sapwood, etc. Thus grading has come to mean as intelligent choice of timber for specific purposes. With the possibilities of improving the properties of timber and timber products, and with improvements in conversion and processing techniques, grading rules can and should be altered from time to time for rational utilization of timber keeping in view the primary factors of safety and also economy. At this stage it may be also kept in view that grading of timber, even by virtue of the terminology employed, has a significant impact on timber trade and its economy in general; for example, what can be grade I, II and III in terms of strength, if termed as 'select grade', 'Grade I' and 'Grade II' has a different impact on the economy. Similarly if classification of the whole lot is made into two or three groups as against four or five, then again it has an impact on price structure commercially. Sometimes a defect which is not accepted for one purpose, may be preferable for some other purpose (for example, a piece with too much distorted grain unsuitable for structures, can be suitably cut and matched for giving a beautiful decorative appearance). Thus, grading of timber is a complex problem, and so several purchasers and sellers prepare their own grading specifications. Thus in spite of best efforts for unifying several grading specifications and paractices, the railway, the MES and the PWD still continue to have their own specifications, various forest departments in the country have their own grading specifications and there have also been some differences in methods of measurement of lengths of logs and converted timber, girths and diameters of logs, and also in the calculation of volumes and measurements of defects. Even in foreign countries the Lumber Manufacturing Associations, dealing with some specified species and recommending the same for specific end uses, have their own grading rules. In other countries where grading is practised on large scale, recognized inspecting organizations have also come up which issue certificates of grading and take upon themselves the responsibility for quality of the material. In the context of such varied considerations in grading, some attempts have been made in FAO grading rules, as also adopted in some IS specifications, to standardize methods of measurements and quantify the defects and evaluate their cumulative effects, which cannot be exactly predicted otherwise [IS : 3364 (Parts I and 2)-1976]. Such recent attempts on the part of technologists to bring a mathematical pattern for exactness, for a subject which otherwise is too arbitrary and complicated to avoid disputes, can be viewed only to serve as a general guide with wide limitations and tolerances.

2.5.2 *Systems of Grading* — In India, at present there are several systems of grading as practised by various sellers and purchasers, and as also codified in various Indian Standards according to end uses of timber such as those intended for further conversion (IS : 190-1974 and IS : 1326-1976), for cut sizes (IS : 1331-1971 and IS : 2377-1976), for teak squares (IS : 3731-1966), for measurements and calculation of volumes [IS : 2134-1981, IS : 3364 (Parts I and 2)-1976 and IS : 2184-1973], for specific uses such as lorry bodies, aircraft, etc (IS : 2176-1979 and IS : 1329-1975), and for constructional timbers (IS : 3629-1966). All these specifications can be broadly classifed as follows:

a) Grade classification based purely and sometimes arbitrarily on (1) dimensions and (2) general appearance.

b) Grade classification based on the best ultimate use of logs or converted material.

c) Grade classification based purely on defects and rough estimates of our turn of utilizable material.

d) Grade classification based purely on evaluation of 'units of defects' and fixing the number of units permissible for a specified volume in each grade.

In spite of a high degree of standardization as indicated above, and also attempts to unify and codify some of the common practices, the present status of grading technology cannot be said to have attained any perfect stage acceptable to all, and yet it is widely felt that some sort of grading is very necessary for the selection and payments to be made for the timbers. On a recent survey of demand and stocking position, the preferred sizes of converted timber, standardized (IS : 1331-1971) and codified in NBC are given in Table 3. However, IS : 4891-1968 gives preferred cut sizes and tolerances of structural timbers further divided for: (a) roof timbers, (b) roof purlins, rafter and floor beams, (c) partition framing, covering, and (d) centering. These are given in Tables 4 to 6.

Preferred sizes for doors, windows, ventilator frames, etc, can be found in IS : 1003(Part 1)-1976, IS : 1003(Part 2)-1966, IS : 2191(Parts 1 and 2)-1980, IS : 2202(Parts 1 and 2)-1980 and IS : 4021-1976.

TABLE 3 STANDARD THICKNESS AND WIDTHS OF CUT TIMBER NORMALLY AVAILABLE IN MARKETS

THICKNESS (cm)	WIDTH (cm)
1.0	4, 5 and 6 to 12 in steps of 2 cm
1.5	4, 5 and 6 to 18 in steps of 2 cm
2.0	4, 5 and 6 to 24 in steps of 2 cm
2.5	4, 5 and 6 to 30 in steps of 2 cm
3.0	4, 5 and 6 to 14 in steps of 2 cm
4.0	4, 5 and 6 to 30 in steps of 2 cm
5.0	8, 5 and 6 to 30 in steps of 2 cm
6.0	8 to 30 in steps of 2 cm
8.0	8 to 30 in steps of 2 cm
10.0	10 to 30 in steps of 2 cm
12.0	12 to 30 in steps of 2 cm
14.0	16 to 30 in steps of 2 cm
16.0	16 to 30 in steps of 2 cm
18.0	18 to 30 in steps of 2 cm
20.0	20 only

Under each cross-section, the lengths may vary from 1 metre and up, in steps of 5 cm. All dimenssions are given at a moisture content of 20 percent in accordance with ISO recommendations.

NOTE — Many saw mills still cut timber according to the requirements of purchasers. The above is only a rough guide of availability from depots where cut sizes are stocked.

2.5.3 *Measurements and Evaluation* — While it is not intended to describe here in detail all the methods of measurement, a brief mention of some, with particular reference to structural timbers, may be useful. Hence these are discussed below.

2.5.3.1 *Lengths of logs* — To be measured by tapes in metres, rounded off to the nearest lower 5 cm. When the ends are not cut at right angles to the axis of log, the measurement should be made up to the point which will give a full flat cut.

2.5.3.2 *Girths and diameters* — In the case of standing trees calipers are employed for measurement of diameters, and tape for measurement of girth, usually at 'breast-height', that is, 1.5 metres from ground level. In the case of felled logs, girths are incurred by tape at mid length of the log. When diameters are measured, which is not common, it is done at the smaller end, usually by averaging the smallest and largest diameters at that end.

2.5.3.3 *Bark allowances* — All measurements are usually done under bark, but where it

TABLE 4 PREFERED CUT SIZES OF STRUCTURAL TIMBERS FOR ROOF TRUSSES (FROM 3 TO 20 METRES)

(*Clause* 2.5.2)

THICKNESS cm	WIDTH, cm							
2.0	4	5	6	8	—	—	—	—
2.5	4	5	6	8	10	12	14	16
3.0	4	5	6	8	10	12	14	16
4.0	—	—	6	8	10	12	14	16
5.0	—	—	6	8	10	12	14	16
6.0	—	—	—	8	10	12	14	16
8.0	—	—	—	—	10	12	14	16

NOTE — Preferred lengths of timber are : 1, 1.5, 2, 2.5 and 3m.

TABLE 5 PREFERRED CUT SIZES OF STRUCTURAL TIMBER FOR ROOF PURLINS, RAFTERS, FLOOR BEAMS, ETC.

(*Clause* 2.5.2)

THICKNESS cm	WIDTH, cm						
6	8	10	12	14	16	—	—
8	—	10	12	14	16	—	—
10	—	—	—	14	16	18	20

NOTE — Preferred lengths of timber are : 2, 2.5, 3 and 3.5m.

TABLE 6 PREFERRED CUT SIZES OF STRUCTURAL TIMBERS FOR PARTITION FRAMING AND COVERING

(*Clause* 2.5.2)

THICKNESS cm	WIDTH, cm								
1.0	—	5	—	8	10	—	—	-	
1.5		5		8	10	12	16	—	
2.0	—		—	8	10	12	16		—
2.5	-			8	10	12	16	20	24
3.0				8	10	12	16	20	24
4.0	4	5	6	8	10	12	16	20	24
5.0	-	5	6	8	10	12	16	20	24
6.0	—	—	—	—	-	12	16	20	24
8.0	—	—	—	-	10	12	16	20	24

NOTE Preferred lengths of timber are : 0.5, 1, 1.5 and 2m

has to be measured over the bark, appropriate allowance is made for the same depending on the species. On the averge this is 1/16.

2.5.3.4 *Converted timber* Lengths are measured by tape or scale and rounded off to lowest 5 cm. The width and thickness, measured at the narrowest places, are rounded off to the nearest centimetre or millimetre as per individual specification. The face of converted timber are recognized as 'wide face' and 'narrow face' unless they are of square cross-section. The 'edges', particularly in planks, are sometimes referred to 'narrow faces' but the words 'edge of a face', as in structural grading terminology, refers to intersection of two perpendicular faces, that is, 'corner' of a face.

2.5.3.5 *Volume calculations* - Volume is generally obtained by reference to prepared tables [IS : 2134-1981 and IS : 336 (Parts 1 and 2)-1976] based on quarter-girth formula for logs, that is, volume = (¼ girth)^2 × length. But in view of the present day developments in selvicultural practices and wood technology, the general trend is to calculate volume on the basis of 'true volume' of log considered as a cylinder ($\pi r^2 h$).

2.5.3.6 *Conversion of sizes to the required moisture content* - The nominal sizes prescribed in IS : 1331-1971 for stocking in depot are given at 20 percent moisture content as required in some international standards, but taking into consideration the shrinkage effects, the size obtainable at the required moisture content (that is, equilibrium with the atmospheric humidity) is given by the formula:

$$d'_m = d_m \left[1 - \frac{K(m - m')}{100} \right]$$

where

d_m = given dimension at the given standard moisture content, m;

d'_m = required dimension at the observed moisture content m'; and

K = a factor, representing shrinkage per unit moisture content on the basis of dimensions at the standard moisture content m. This depends upon fibre saturation point, normal shrinkage values as determined by standard procedures which, in turn, is roughly estimated as dependent on specific gravity ρ, by the formula $K = 0.41\ \rho$. But for ready use, K is recommended to be 0.2 for all species of specific gravity below 0.6 and $K = 0.3$ for species of specific gravity above 0.6. When the specific gravity is not known K can be equated to 0.25 as the nearest approximation.

NOTE Where greater accuracy is required in individual species the exact figures of change in percent, per unit moisture content (even separately for radial and tangential directions, if so required) may be calculated from the following formula:

$$\frac{1}{K} = \frac{f - p}{S_p} - \frac{f - 20}{100}$$

Where

K = the required change in percent per unit moisture content corresponding to the approximate value of 0.2 or 0.3;

f = fibre-saturation point of the species in question;

p = 12 percent or 0 percent as the case may be corresponding to the shrinkage value taken (average of both may be taken, if necessary); and

S_p = standard shrinkage value from green to dry ($p = 12$) or over-dry ($p = 0$) as calculated by method given in IS : 1708-1969.

The values of f and S_p may be obtained from the various publications of the Forest Research Institute and Colleges, Dehra Dun.

2.5.3.7 *Defects* — Methods of measurement of defects have been standardized in IS : 3364(Part 1 and 2)-1976 and according to their sizes, shapes or numbers, etc, the 'units' are given, which represent approximate degrade of the utilizable material. These defects are discussed very briefly in the following clauses. For identifying the defects *see* **2.4.7**. All measurements of defects are made correct to 1 mm and the units are evaluated correct to second decimal place on the basis of 10-metre length of the material; For defects not covered in the following clauses, and which are suspected to cause degrade, they may be measured and evaluated as 'equivalent defects', guided by their appearance, size, location and distribution with reference to the whole piece and the purpose to which it is put.

a) *Check* — Measured by length and width of maximum separation of fibre up to 2 mm. When such checks are numerous on any surface they are evaluated on the basis of average length and the effective area expressed as a percentage of whole area on which they appear. For affected areas from 20 to 50 percent and for checks ranging in length from 5 to 50 cm, the defect units range from 0.01 to 1.60. Checks more than 2 mm are generally evaluated as shakes.

b) *Decay or rot* — This is estimated as percentage of affected area to entire area of the surface. The units of defects for decay ranging from 1 to 50 percent varies from 0.01 to 0.5.

c) *Flutes* — These are measured by their lengths on the longitudinal surface of logs and depths at their maximum points which is sometimes expressed as percentage of the girth of the log. Defect units for lengths varying from 0.5 to 5 metres for different depths ranging from 5 to 25 cm, the units of defects vary from 0.04 to 1.66.

d) *Holes* — Except pin holes, others are expressed by their diameters. When in large numbers, they are expressed as so many per 100 cm^2 to limit their occurance in various grades. In terms of defect values for varying concentrations of holes from 1 to 5 per 100 cm^2, and for the diameter of the largest hole ranging from 5 to 10 mm, the defect values range from 0.01 to 0.90.

e) *Inbark* — Measured and evaluated in the same way as knots.

f) *Knots* — The maximum diameter of a knot is taken as its size though some practices exist in some places to take the average of the maximum and the minimum, or the average of maximum and of the one perpendicular to it at the pith centre of the knot. When a group of knots exist together, the mean of the maximum diameters of all knots at the area are taken. For number of knots ranging from 1 to 15, and the average maximum diameter of knot varying from 5 to 20 cm, the defect values vary from 0.1 to 4.50, for other sizes and number proportionate values can be taken. Double values are taken for unsound and decayed knots.

g) *Shake* — Except star shakes, all the other shakes are measured by the length and maximum width of the opening. It is presumed that the width is generally proportional to the depth also. However, in NBC, for structural grades, only the depth at its maximum point is recommended to be measured. For length of shake from 2 to 20 cm and for the width ranging from 0.2 to 2.5 cm, (provided the area of cross-section does not exceed 0.5 m^2), the defect values range from 0.06 to 1.74. For areas of cross-section exceeding 0.5 m^2, the values are halved. In the case of star shake, the large shake is taken for consideration and the defect values are multiplied by half the number of shakes of the group.

h) *Splits* — In the case of splits which appear on two surfaces, the length on the longitudinal surface and depth on the perpendicular surface (that is, the end surface in cross-section) are measured. For lengths ranging from 0.25 to 4 metres, and for depths from 1 to 4 cm, the defect values range from 0.06 to 1.86.

j) *Cross grain* — This is measured by the slope of the grain with reference to the edge of the major on which it appears. When present on both the adjacent surfaces of a piece of timber the combined slope is given by

$$\frac{1}{X^2} = \frac{1}{A^2} + \frac{1}{B^2}$$

where

$\frac{1}{X}$ = combined slope, and

$\frac{1}{A}$ and $\frac{1}{B}$ = slopes on the adjacent surfaces

The slope ranging from 5° to 50° are given defect values ranging from 0.2 to 1.00. In the case of spiral grain for logs, the same values as above are given.

k) *Distortion or warp* — This is identified by any deviation in converted timber from a true plane surface causing departure from its original planes. It includes bow, cup, spring, twist and any combination thereof.

2.5.4 *Guiding Principles* — Reference may be made to IS : 6534-1971 for full details, special terminology, and code of ethics for inspection and reinspection. It should be kept in mind by all concerned that all systems and procedures of grading discussed above are somewhat arbitrary, based only on available experience, brought on, as close as possible, to a technological pattern, and cannot be claimed to be of exact assessment of the quality of material. Thus, grading of a whole consignment becomes preferable to grading of individual pieces. In a lot, where most of the pieces fall in a particular grade, any single individual piece having one of the defects slightly in excess of permissible limits for a particular grade may not necessarily qualify for the expected properties of the grade, as the location, distribution and combination of the defects play a major role. In this connection the discretion of the grader comes into play quite often. A small latitude of 5 percent is generally allowed for personal judgement of the inspectors and graders who have to exercise a balance of consideration between the availability of the material, end use, urgency of requirement, and costs involved, etc. Experience and integrity of graders and inspectors will add to a great extent the acceptance of the material by all concerned.

2.5.5 *Stress Grading and Structural Grading* — These two terms are often used synonimusly. However, sometimes a small difference is conceived; the former referring to a system by which the materials or species as a whole, are graded purely by consideration of the principal stresses that come into play, (that is, evaluating how the species, the sizes together with defects can bear the required stresses or what percentage of basic stress it can bear). The latter, that is, structural grading is a system by which the material graded is on the basis of evaluation of supposed effects of visible defects on general strength of the material, irrespective of what type of stresses are likely to arise when employed in the structure. Obviously the distinction is only narrow and theoretical in nature particularly for visual selection. Stress grading machines are in vogue in other countries, but they have not yet been introduced in India even for research and development activities. Machine grading depends on the principle of relationship between stiffness and strength, and brings out not only cumulative effects of all visible defects, but also effects of any hidden features in structural members.

2.5.5.1 The structural grading of Indian species is covered by IS : 3629-1965 and IS : 1629-1971. In India three grades are recognized. The select grade contains defects which do not reduce strength by more than 12.5 percent of fundamental, that is, ultimate stresses; the Grade I also known as 'standard grade' contains defects which reduce strength by more than 12.5 percent but not more than 25 percent and Grade II also known as 'common grade' contains defects which reduce strength by more than 25 percent but not more than 37.5 percent. The safe working stresses of selection grade are 7/6 times those of standard grade (Grade I) and working stresses of common grade (Grade II) and 5/6 times those of standard grade. The permissible sizes of some defects under the different grades as accepted in NBC are given in Table 7. In addition to the above consideration for grading of structural timbers, the other criteria which limit the use of timbers are given below:

a) Light timber having a weight less than 75 percent of averge weight indicated in col 12 of Appendix H are rejected.

b) Defects not permissible in any grade are loose grain, splits, reaction wood, decay, knot and holes with live infestation.

c) Wanes are permitted provided they are not combined with knots and they do not adversely influence bearing areas and nailing edges, and general appearance.

3. MECHANICAL AND PHYSICAL PROPERTIES OF INDIAN WOODS

3.1 Methods of Test and Evaluation of Properties

3.1.1 Accurate evaluation of basic properties of timber, which exhibits wide variations, is an important base for establishing design functions. For obtaining a confident average of a given species, the samples should be representative of different portions of a tree, different trees, different localities in India, and the tests should be conducted under highly standardized procedures to obtain maximum reliability and repeatability of the data. For this purposes, tests on timber are conducted: (a) in small clear specimen in accordance with IS : 1708-1969 and (b) on structural sizes in accordance with IS : 2408-1965. The former are conducted as a routine on all species in the green condition and in the dry condition. Greater emphasis is, however, given on the results of green condition as the results are more reliable, being free from influence of any drying stresses introduced in the timber. Also from the point of design, they are safer values because the strength properties in green timber are lower compared to strength of dry timber, though eventually the larger sections of timbers used in structures become dry and attain a moisture content in equilibrium with atmospheric humidity of the locality where they are placed. The standardized details of sizes of test specimens, rate of loading, surface on which load is applied, and the properties evaluated as routine are summarized in Appendix D but the exact procedures required to be essentialy followed are described in greater detail in IS : 1708-1969. A set of formulae employed to evaluate the properties obtained in different tests are also given in Appendix D for ready reference and convenience. The data obtained on the basis of the above procedures and formulae, when obtained in accordance with the sampling procedures prescribed in IS : 2455-1974, are

TABLE 7 PERMISSIBLE DEFECTS FOR CUT SIZES OF TIMBER FOR STRUCTURAL USE

(*Clause* 2.5.5.1)

All dimensions are in millimetres

Sl. No.	Defects	Grade 1	Grade 2	Grade 3
(1)	(2)	(3)	(4)	(5)
i)	Wane	Shall be permissible at its deepest portion up to a limit of 1/8 of the width of the surface on which it occurs	Shall be permissible at its deepest portion up to a limit of 1/6 of the width of the surface on which it occurs	Shall be permissible at its deepest portion up to a limit of 1/4 of the width of the surface on which it occurs
ii)	Worm holes	Other than those due to powder post beetles are permissible	Other than those due to post beetles are permissible	Other than those due to powder post beetles are permissible
iii)	Slope of grain	Shall not be more than 1 in 20	Shall not be more than in 15	Shall not be more than 1 in 12
iv)	Live knots:			

Width of Wide Faces of Cut Sizes to Timber *Max*	Permissible Maximum Size of Live Knot on		Permissible Maximum Size of Live Knot on		Permissible Maximum Size of Live Knot on	
	Narrow Faces and 1/4 of the Width Face Close to Edges of Cut Size of Timber	Remaining Central Half of the Width of the Wide Faces	Narrow Faces and 1/4 of the Width Face Close to Edges of Cut Size of Timber	Remaining Central Half of the Width of the Wide Faces	Narrow Faces and 1/4 of the Width Face Close to Edges of Cut Size of Timber	Remaining Central Half of the Width of the Wide Faces
(1)	(2)	(3)	(4)	(5)	(6)	(7)
75	10	10	19	19	29	30
100	13	13	25	25	38	39
150	19	19	38	38	57	57
200	22	25	44	50	66	75
250	25	29	50	57	75	87
300	27	38	54	75	81	114
350	29	41	57	81	87	123
400	32	44	63	87	96	132
450	33	47	66	93	99	141
500	35	50	69	100	105	150
550	36	52	72	103	108	156
600	38	53	75	106	114	159

v) Checks and shakes

Width of the Face of the Timber *Max*	Permissible Depth *Max*	Permissible Depth *Max*	Permissible Depth *Max*
(1)	(2)	(3)	(4)
75	12	25	36
100	18	35	54
150	25	50	75
200	33	65	99
250	40	81	120
300	50	100	150
350	57	115	171
400	66	131	198
450	76	150	225
500	83	165	270
550	90	181	300
600	100	200	—

presented according to a system prescribed in the same standard. While most of the engineering laboratories are not always able to follow the above presented procedures for sampling and layout of the tests, and presentation of data, the regular laboratories like Forest Research Institutes where systematic studies are carried out as a routine on all species, follow the above procedures, and the data presented by these organizations can be taken as most authentic. However, in organizations like most of the colleges, engineering laboratories, where they do not or cannot follow the detailed testing procedures prescribed in IS : 2455-1974, for various reasons they do adopt the standard sizes and rates of loading, etc, which will give data on a limited base and can be considered sufficient for comparison with any acceptable limits of confidence and for further evaluation for purpose of local design considerations, if any.

3.1.2 The tests of structural sizes given in **3.1.1** are described in greater detail in IS : 2408-1963. The main object of testing in the larger sizes, according to the methods prescribed in this standard is to serve as a cross check on the design data wherever necessary and wherever such large sized material can be spared for such tests. They serve to check the established relations between the strength functions based on small clear specimens, and the permissible stresses in structural timber. When such tests are done on a large number of timbers and data become available for study, they can also be used to develop and improve upon the grading rules for different structural timbers and different strength groups. In a way they serve to determine the effect of defects and other variables on the strength of timber in structural sizes and study all relevant factors as are necessary for specific structural designs. As described in IS : 2408-1963, while the 'major tests' are conducted on large-sized material for bending, compression parallel to grain, and compression perpendicular to grain, the 'minor tests' are conducted according to IS : 1708-1969 on defect-free small clear specimens cut from matched portions of material intended for 'major tests' or from undamaged portions of material already subjected to such 'major tests'. The scheme of tests for major tests and formulae are given in Appendix E.

3.1.3 From the data thus obtained, the 'working stresses', also known as 'permissible stresses' are derived. These are discussed in **3.3** alongwith factors of safety, etc, and they are the stresses actually used in designs.

3.1.4 The above strength data, called 'suitability indices', are used for a quick and comparative assessment of timber species in a quantitative manner for various industrial and engineering purposes (*see also* **2.3.6** and Table 2). These are based on basic strength data on physical and mechanical properties, evaluated on small clear specimen by selecting mechanical and physical properties, which play principal or auxiliary roles for particular end use, such as strength as a beam, suitability as a post, tool handles, agriculatural implements, etc. The selected basic properties are given appropriate weightage according to relative important role they play. The variations in green and dry conditions are also taken into consideration. The average value obtained by adding the computed and adjusted values of the concerned properties is usually compared with a similar value of a well known species commonly used for the purpose in view, usually with teak, which is widely used and well known in its behaviour. It should be remembered that these suitability indices are not to be used for design purposes but they serve only for comparative selection of different species based on limited and arbitrary considerations. A typical example of deriving such indices is given in Appendix J. The values for a few selected species are given in Table 8. These figures have

TABLE 8 COMPARATIVE SUITABILITY INDICES IN TERMS OF TEAK AS 100 FOR SOME IMPORTANT PROPERTIES (FIGURES ARE ADJUSTED TO NEAREST 5)

(*Clause* 3.1.4)

Sl No.	Species and Trade Name	Strength as a Beam Comparative Index	Suitability as a Post or Strut	Shock Resisting Ability	Surface Hardness	Refractoriness (Splitting Co-efficients)	Nail or Screw Holding Property Comparative Index
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	*Adina cordifolia* (haldu)	80	80	70	100	60	100
ii)	*Cedrus deodara* (deodar)	80	85	55	65	85	80
iii)	*Dalbergia sissoo*, (sissoo)	95	90	130	120	80	115
iv)	*Dysoxylum malabaricum* (white cedar)	90	95	110	90	80	100
v)	*Hopea glabra* (hopea)	130	130	145	205	55	145
vi)	*Mangifera indica* (mango)	75	75	90	85	60	100
vii)	*Mimusops littoralis*, (bullet wood)	145	145	145	230	105	150
viii)	*Ougeinin dalbergioides* (sandan)	80	80	105	130	80	120
ix)	*Shoree robusta* (sal)	115	110	130	150	90	125
x)	*Xylin xylocarpa* (irul)	105	110	80	180	60	120

been in wide use in various forest departments and depots for comparative evaluation only.

3.2 Factors Affecting Strength Properties

3.2.1 Being a biological material, naturally the cell size, the thickness, and orientation of wood cells have necessarily some influence on the strength properties and these depend on inherent hereditary characteristics and growth condition (such as soil, climate, locality and selvicultural methods employed). It has not been possible to study these effects in any systematic manner, but empirically some conclusions have been arrived that material of the same species do not have very significant difference from commercial points of view, and their densities would reflect the serious differences, if any. It may be remembered that in actual use, considerable factors of safety are employed on a statistical average. Factors like age of tree, position of wood in the tree, season of felling, natural or plantation grown wood, condition of the tree when felled (that is, whether dead or green or twisted or containing abnormalities like streaks, etc), also come up often, but for engineering purposes, when material has to be selected from depots and yards it would not be possible to lay much importance to the above as these pertain to the quality of the tree in standing condition only. However, most of the laboratories engaged on systematic tests from selected trees in the forests, keep appropriate records of the same. The only criteria of growing condition which can be judged at the time of selection and use of timber for engineering purposes is the rate of growth as reflected by the width of the growth rings on the cross-section of timber pieces. In the same species, too wide rings or too narrow rings may indicate slightly lower strength than those with average growth. Presence of distortions or abnormalities in the wood structure as identified in growth rings may cause undue concentrations of stress at those places. However, keeping in mind that the width of the ring may also vary from bottom to top or from pith to periphery, this should not be taken as too serious a criterian for strength particularly as compared to specific gravity. By and large studies on variation of strength due to causes as discussed above have so far been oriented more to study variations in specific gravity which in turn reflects the strength.

3.2.2 Specific gravity of wood is the basic property which has considerable influence on the strength properties, so much so in the event of non-availability of actual strength data, the same can be computed by the formulae developed on the basis of studies on more than 150 species of India, and confirmed on quite a large number of species subsequently tested. The general formula is given by:

$$S = K\rho^n$$

where

S = strength, and

ρ = standard specific gravity based on oven-dry weight and volume at test (*see* IS : 1708-1969)

K and n are constants of the particular property. The formulae with K and n values are given in Table 9. Similar formulae were obtained also for working stresses for standard grade of timber under different locations. These are given in Table 10. It may be seen from these formulae that in most of the properties n is unity, thus indicating a linear relationship. However, it may be noted that all properties do not vary with specific gravity in the same manner to expect the same proportionate increase or decrease as n, the power index for ρ in some of the properties, is not unity. No data is available in India for variation of strength with specific gravity within the range of any single species, but in USA a formula as given below is used.

$$\frac{S_1}{S_2} = \left(\frac{\rho_1}{\rho_2}\right)^q$$

where

S_1 = strength corresponding to ρ_1,

S_2 = strength corresponding to ρ_2, and

q = on an average 1.7 (varying between 1.25 and 2.25) for various properties

3.2.3 *Moisture Content* — This affects the strength of wood in dry condition. In green condition, that is, well above the so called fibre saturation point (fsp) which is between 20 and 30 percent for most of the species, the strength is not affected and is the lowest obtained on the species. In the dry condition, the strength increases as the moisture content is reduced and is given by the formula :

$$\text{Log } S_m = a - bm$$

where S_m is the strength at moisture content m, and a and b are constants for the species and properties in question. The formula is sometimes known as Madison formula, and although evolved for timbers in USA, the same has been fairly successfully used for Indian timbers also. By knowing strength at any two given moisture content, the values of a and b can be calculated and used for knowing strength at any other moisture content. Usually, by knowing strength S of green timber, that is, S above the fibre saturation point, f moisture content (S being constant at any moisture content in the green condition) and also by knowing strength in dry condition at any determined moisture content, the strength value at the required air-dry condition (12 percent) is computed for presentation of standard data; and for purposes of comparison of

TABLE 9 EFFECT OF SPECIFIC GRAVITY ON ULTIMATE STRESSES

(*Clause* 3.2.2)

PROPERTY	UNIT	GREEN CONDITION	AIR DRY CONDITION
Static Bending			
Modulus of rupture	kg/cm^2	1153ρ	1495ρ
Fibre stress at elastic limit	kg/cm^2	682ρ	865
Modulus of elasticity	1000 kg/cm^2	165.9ρ	194.8ρ
Impact bending			
Fibre stress at elastic limit	kg/cm^2	1665ρ	1853ρ
Height of drop	cm	$163\rho^{1.25}$	$140\rho^{1.25}$
Modulus of elasticity	1000 kg/cm^2	236.9ρ	270ρ
Compression parablel to grain			
Compression stress as elastic limit	kg/cm^2	414ρ	464ρ
Maximum Crubling stress	kg/cm^2	579ρ	825ρ
Modulus of elasticity	1000 kg/cm^2	185.8ρ	209.2ρ
Compression perpendicular to grain			
Compression stress at elastic limit	kg/cm^2	$176\rho^{1.75}$	$191\rho^{1.5}$
Compression stres at elastic limit	kg/cm^2	$176\rho^{1.75}$	$191\rho^{1.5}$
Shear			
Radial	kg/cm^2	135ρ	161.7ρ
Tangential	kg/cm^2	151.2ρ	175.8ρ
Tension to grain			
Radial	kg/cm^2	66.4ρ	53.1ρ
Tangential	kg/cm^2	82.3ρ	75.9ρ
Hardness			
End	Load in kg	$1232\rho^{1.75}$	$1490\rho^{1.75}$
Radial	(standard	$1376\rho^2$	$1669\rho^{2.25}$
Tangential	steel ball	$1211\rho^{1.75}$	$1524\rho^2$

strength properties of different species in the dry state. As the constants are not the same for all properties and as it is sometimes cumbersome to quickly evaluate the influence of moisture, the change in strength properties for 1 percent decrease in moisture below the fibre saturation point is given in Table 11 for some important properties.

No such data is available exclusively for Indian species but as the strength-moisture relationship employed in India is still the same as 'Madison formula' employed in the USA. It is believed that Table 11 roughly holds for Indian species also. However, in some of the literature from Forest Research Institute, Dehra Dun the formula $S \times M = K$ has been confidently employed in close ranges, where S is the strength, M is the moisture content below fibre saturation point (fsp) and K is the constant for the species and the property.

3.2.4 *Defects* — Defects have major influence on strength properties of timbers particularly when they are used for structural purposes, and hence the structural grading of timber depends largely on the nature and also location of defects. These are discussed here briefly in so far as they effect the strength properties. Although it is not proposed to discuss here all the research developments in this field, it is useful to remember that all defects do not affect the strength to the same extent and that the same defect does not reduce the strength to the same extent at all positions of a stressed member. It would also be not possible to evaluate quantitatively the exact cumulative effect of all defects on a structural member of a stressed member, though attempts have been made to define the defects and their cumulative role in terms of quantitative figures, called 'units of defects' assigned to them as in some grading rules of Food and Agriculture Organization (FAO) for Asia and Pacific region, and which, to some extent, have also been adopted in IS : 3364 (Parts 1 and 2)-1976.

TABLE 10 WORKING STRESS — SPECIFIC GRAVITY RELATIONSHIP

SL No.	WORKING STRESS CONDITION	STRESS IN kg/cm²		
		Inside Location	Outside Location	Wet Location
i)	**Extreme fibre stress in beams for broad leaved trees (non-conifers)**	300ρ	250ρ	200ρ
ii)	**Extreme fibre stress in beam for coniferous species**	185ρ	160ρ	130ρ
iii)	**Shear along the grain**	26.5ρ	26.5ρ	26.5ρ
iv)	**Horizontal shear in beam**	18.5ρ	18.5ρ	18.5ρ
v)	**Maximum crushing stress along grain**	205ρ	185ρ	150ρ
vi)	**Compressive stress across grain**	$110\rho^{1.5}$	$85\rho^{1.5}$	$70\rho^{1.5}$

TABLE 11 EFFECT OF 1 PERCENT CHANGE IN MOISTURE CONTENT UPON THE STRENGTH PROPERTIES

PROPERTY	PERCENTAGE
Static Bending	
a) Fibre stress at elastic limit	5
b) Modulus of rupture	4
c) Modulus of elasticity	2
Impact Bending	
a) Fibre stress at elastic limit	3
b) Height of drop of hammer causing complete failure	−½
Compression Perallel to Grain	
a) Fibre stress at elastic limit	5
b) Maximum crushing strength	6
Compression Perpendicular to Grain	
a) Fibre stress at elastic limit	5½
Maximum Shear Stress Parallel to Grain	3
Maximum Tensile Stress Perpendicular to Grain	1½
Hardness	
a) End grain	4
b) Side grain	2½

3.2.4.1 ***Grain angle*** — The strength in any direction (S_θ) making an angle θ with the direction of fibres (that is, grain) is given by the following formula popularly known as Hankinson formula:

$$S_\theta = \frac{S_0\ S_{90}}{S_0 \sin^2\theta + S_{90} \cos^2\theta}$$

where

S_0 = strength in the direction of grain, and

S_{90} = strength in the direction perpendicular to grain.

The nature of the equation indicates that the rate of reduction in strength is somewhat rapid up to about 30° to 40° and thereafter the rate is comparatively slow. However, taking into consideration the tolerance limits of permissible stresses, and the various lengths commonly used as structural members, the following limits of ratios of slope of grain for the different stresses are recommended in various text books:

a) Compressive strength	1 in 10
b) Modulus of elasticity	1 in 15
c) Modulus of rupture	1 in 20
d) Shock resistance	1 in 25

But in NBC, for purposes of selecting the required grade of timber the following slopes have been permitted irrespective of stressess concerned (*see also* **2.5.6** and Table 7).

Grade 1	1 in 20
Grade 2	1 in 15
Grade 3	1 in 12

Also a modification factor is suggested for design purpose, for different slopes of grain for beams joists and ties, and also separately for posts and columns.

3.2.4.2 *Knots* In view of the deviation of grain around a knot, not only the strength is affected but stress concentrations may take place. Hence the position of knot in a structural member is equally or even more important than the size, shape or soundness of the knot. As timber is weaker in tension across the grain than in compression, the position of knot in a tension member or on the tension side in bending, affects the strength more than on compression side. Knots do not affect stiffness, and as such they are not considered seriously in long columns where stiffness is the controlling factor as against short and intermediate columns where strength comes into more prominent play. In NBC the size and position of knots for different widths of the face are included. (*see* **2.5.6** and Table 7).

3.2.4.3 *Checks, shakes and splits* - These primarily reduce the resistance to shear proportionate to the area of separation of fibres. However in prescribing permissible limits, and in conformity with the unusual methods of measuring such defects, one or more of the length, width and depth only are indicated. In NBC, the depth is prescribed for different widths of the faces on which they occur for different grades.

3.2.4.4 *Pith and boxed heart* - The presence of pith as such is not of considerable importance, if otherwise sound and not decayed. However, the almost certain existance of shakes, checks, etc, are to be considered on the basis of discussion in **3.2.4.3**.

3.2.4.5 Decay and sapstain which can be identified as discussed in **2.4.7** (b) will affect the strength depending upon their condition and area attacked and nature of breakdown of wood cells, brashness or brittleness may appear even in the incipient stage. However, sapstain may not be so serious, unless shock-resistance or toughness of the stressed member is in picture. It is, however, imperative in all cases, that there should be no cause for increasing any form of fungal attack in actual use. NBC lists decay under prophibited defects for all structural timbers.

3.2.5 *Treatments* -- Very often doubts arise whether a particular type of preservative treatment or seasoning increases or decreases the strength of timber. Several investigations have revealed that there will be no variation in strength due to treatment as such, if properly done, but any changes caused due to the methods of treatment employed, such as changes in moisture content or destruction of wood cells due to any induced stresses, pressures and temperatures, may affect the strength accordingly. Sometimes pretreatment operations, such as incising, steaming, etc, may affect the strength if not properly done. Similarly no difference in strength should be expected between well kiln-dried timber and properly air-dried timber of comparable moisture contents.

3.2.6 *Temperature* -- The effect of temperture on strength properties of wood, particularly when used as structures, is not generally considered, except as a cause for combinstion under very high temperatures, or developing additional stresses due to moisture movement or developing cracks in the member. However, laboratory investigations have indicated some interesting results of academic nature and consequently of importance in standard testing. Most strength properties increase at temperatures above the room temperature and reduce below the room temperature more or less linearly though not very significantly in all cases. The increase or decrease depends upon specific gravity, moisture content and type of stress, and also on the duration for which the material remains at that temperature. Due to poor conductivity naturally the time factor for the entire member to attain uniform temperature is important.

3.2.7 *Age of Wood* - Sometimes there is an unfounded belief that wood stored for a long time may lose its strength. If well protected against destroying agents like fungii, insects, weathering, etc, old wood is as strong as fresh wood properly seasoned to equilibrium moisture content. Even in service, properly designed, protected and maintained structures, there should be no loss in strength as borne out by numerous century old structures. It should however be kept in mind that wood, unlike other materials, creeps under ordinary temperature if the applied load is high, that is, above what is called 'limit-of-plastic-flow'., It is for this reason that appropriate factors are introduced for deriving working stresses (*see* **3.3**) and also a suitable modification factor is further introduced in designs (*see* **5.1.3** and Table 17).

3.2.8 Besides the above, there are other factors which affect the strength of wood and are of importance not so much at the time of consideration of the use of the material for structures, but at the time of evaluating the strength properties in the laboratories. It will be useful for the designer to understand these as he will then be able to understand the background of the data he will be employing. These factors are given below and have been standardized (IS : 1708-1969) to obtain the safest and repeatable values apart from other considerations of economy.

3.2.8.1 *Rate of loading* - As wood elements are partly elastic and partly plastic, the mechanical behaviour of the material as a whole, that is, the full strength obtained as well as the neture of failure at ultimate stress depends very much on the rate at which load is applied on the test specimen, and there is a need for standardization of this factor for comparable results. With increase in the rate of loading, there is generally an increase in strength properties. At impact loads, that is, sudden loads the strength is nearly twice than under slowly increasing loads. The following are the formulae used for the speed of moveable heads of machines:

a) The load shall be applied continuously and with a uniform motion of the movable head throughout the test so as to produce a rate of strain of 0.001 5 cm per cm of outer fibre length per minute at the point of maximum bending moment. The required head speed shall be calculated from the following formula in the case of simple beams:

$$N = \frac{Za}{3d} \times (3L - 4a)$$

and for third point loading, this becomes:

$$N = \frac{ZL^2}{5 \times 4\ d}$$

where

N = head speed in cm per minute,

Z = unit rate of strain of outer fibre in cm per cm per minute,

a = distance from support to nearest load in cm,

L = span in cm, and

d = depth of the specimen in cm.

b) The rate of loading shall be constant throughout the test and shall be determined by the following formula:

$$N = 0.029\,1\, d^{4,9}$$

where

N = machine head speed in cm per minute, and

d = depth of specimen in cm.

c) The rate of loading shall be constant throughout the test, and shall be calculated from the following formula:

$$N = 0.0015\ L$$

where

N = machine head speed in cm per minute, and

L = length of specimen in cm.

3.2.8.2 *Direction of loading* — As wood is an orthotropic material, with presence of radial ray-elements in the structure, the direction of application of load with reference to principle axis of symmetry plays an important role, and hence it needs to be standardized. The strength in the direction of grain is always higher compared to strength across the grain. The strength in tangential direction or tangential plane is higher than in radial direction or radial plane. In case of static bending tests, the load is applied on the heartside (IS : 1708-1969) of tangential plane.

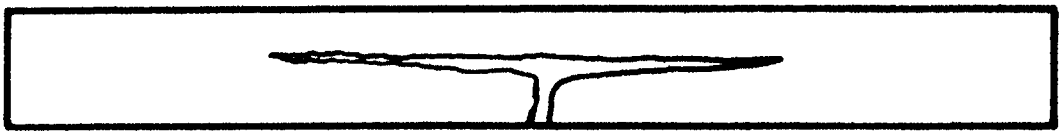
3.2.8.3 *Size and shape of a specimen* Even defect-free, clear specimens of wood have shown different strength values for different sizes of specimen and for different ratios of cross-sectional dimensions, to the length or span of the specimen. In bending, lowest figures are obtained when the ratio of span-to-depth is between 10 and 14. In compression perpendicular to grain, specimen in the shape of cubes have shown lower figure than specimens extending on either side of compression area. In specimens for compressions parallel to grain tests, the length should not be more than 4 times the shortest cross-sectional dimension.

3.2.8.4 Other factors, such as shape of notches in izod tests, shear tests, tension tests, etc, have shown interesting results of academic value and so of standardization value in testing. Similarly methods of gripping and holding specimens in some tests, the accuracy of strain measuring devices, have also indicated variations in ultimate strength. Conditioning of the material to uniform moisture content throughout the specimen under test and throughout the test period is very essential. This becomes all the more necessary in long-term tests like fatigue and creep. In the end, as one cannot always predict the internal nature of the material before test, the final examination of the failure, whether it is appropriate with reference to the type of stress induced in the same, is very necessary to accept or reject the data for presentation. The type of failures that can be expected for the green and dry conditions of the material under different types of stresses are described in some of the text books dealing with timber mechanics. Schematic diagrams of some typical failures under bending, compression and shear are given in Fig. 3 and 4.

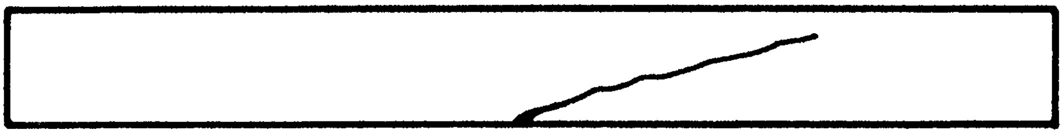
3.3 Factors of Safety and Working Stresses

3.3.1 The usual strength properties reported by many testing laboratories are based on tests on small clear specimen under standard conditions. Naturally they have to be suitably adjusted to meet the conditions that exist in the material and situations of actual use. For this reason the original data are divided by appropriate factors, known as 'factors of safety', and the resultant stresses are known as 'working stresses' or 'safe working stresses' or 'permissible stresses' in timber engineering. These words are used more or less synonimously. At this stage it is necessary, however, to understand the various terms used in proper perspective as they are slightly different in different text books:

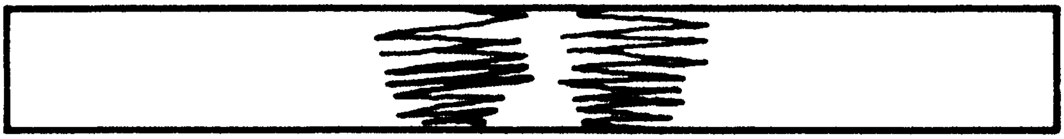
a) The strength properties as obtained on small clear specimen are denoted as 'fundamental stresses' and sometimes as 'ultimate stresses'.



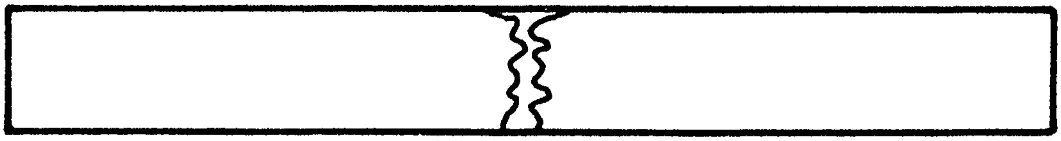
(a) SIMPLE TENSION (SIDE VIEW)



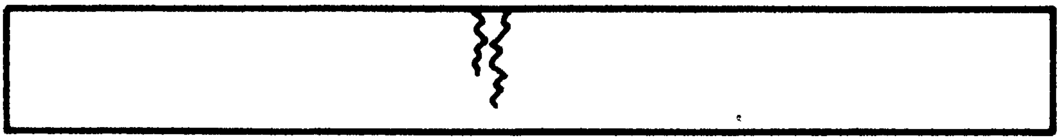
(b) CROSS GRAIN TENSION (SIDE VIEW)



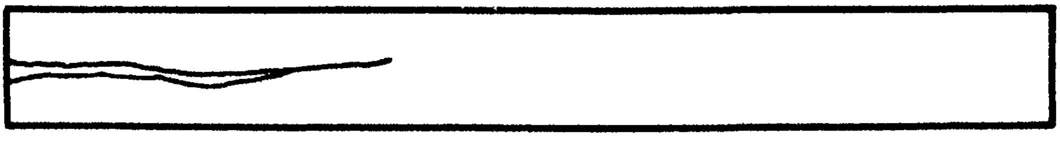
(c) SPLINTERING TENSION (VIEW OF TENSION SURFACE)



(d) BRASH TENSION (VIEW OF TENSION SURFACE)



(e) COMPRESSION (SIDE VIEW)



(f) HORIZONTAL SHEAR (SIDE VIEW)

FIG. 3 TYPES OF FAILURES IN BENDING

b) Timber being a non-homogeneous biological product there would be considerable variation in the properties of the same species. Keeping this in view, and also effects of accidental overloading and longtime loading, the above fundamental stresses are divided by a factor, commonly known as 'factor of ignorance' and these values are known as 'basic stresses'. Thus these represent 'working stresses' for ideal structural

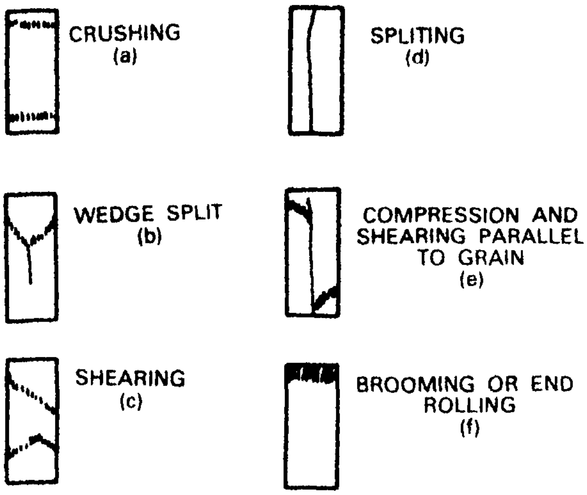


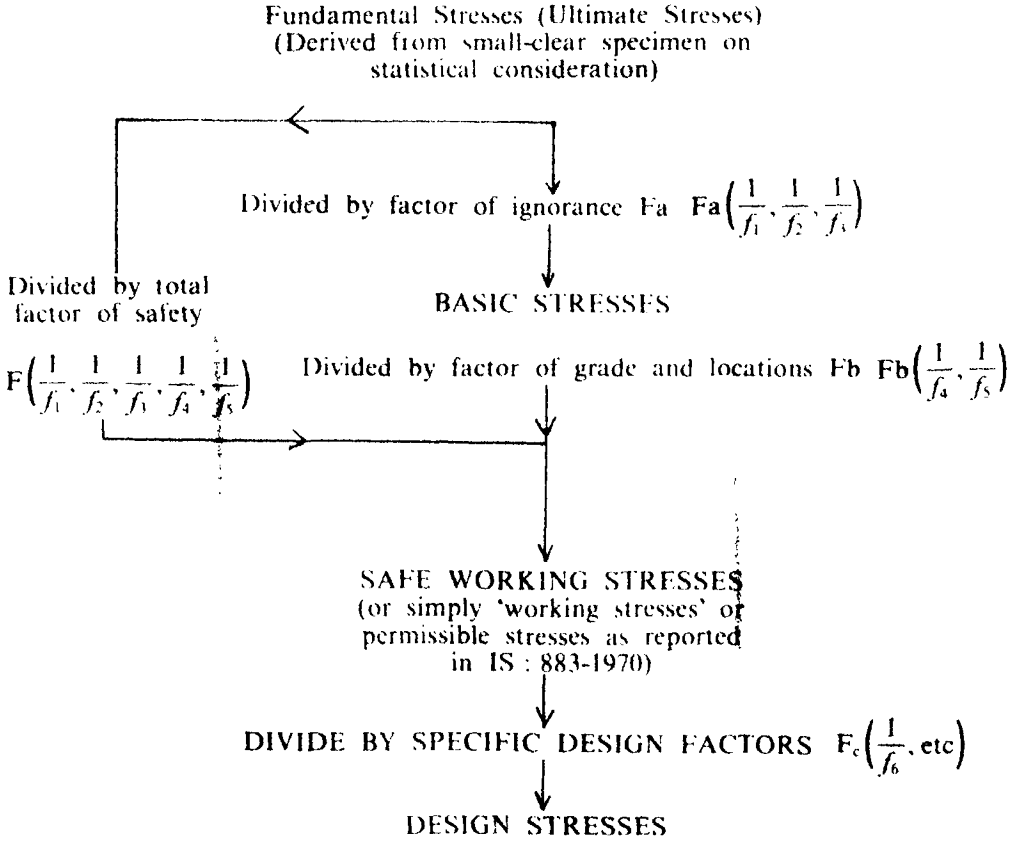
FIG. 4 TYPES OF FAILURES IN COMPRESSION PARALLEL TO GRAIN

component free from defects, that is, without taking grade or condition of use into consideration.

c) Keeping in view, the influence of the grade with its accompanying defects, and condition of use the above are again divided by suitable factors to obtain final 'working stresses' or 'permissible stresses' on which the designer normally starts his work. Thus, the total factor applied on 'Fundamental stresses' has come to be known as 'factor of safety'.

d) Applying further necessary correction factors as may be required in a particular design for the size of members, for inclination of applied loads, for changes in duration of loading, etc, 'design stresses' are obtained.

In NBC and IS : 883-1970 both the terms 'ultimate stresses' and 'basic stress' have been used as synonimous, and working stress has been used for the design stress and no definition has been given for the'permissible stress'. Even though it has been used in the text the derivation of various stresses indicated above can be better understood diagrammatically as below:


Fundamental Stresses (Ultimate Stresses)
(Derived from small-clear specimen on statistical consideration)
Divided by factor of ignorance Fa $Fa\left(\frac{1}{f_1}, \frac{1}{f_2}, \frac{1}{f_3}\right)$
BASIC STRESSES
Divided by total factor of safety
$F\left(\frac{1}{f_1}, \frac{1}{f_2}, \frac{1}{f_3}, \frac{1}{f_4}, \frac{1}{f_5}\right)$
Divided by factor of grade and locations Fb $Fb\left(\frac{1}{f_4}, \frac{1}{f_5}\right)$
SAFE WORKING STRESSES
(or simply 'working stresses' or permissible stresses as reported in IS : 883-1970)
DIVIDE BY SPECIFIC DESIGN FACTORS $F_c\left(\frac{1}{f_6}, \text{etc}\right)$
DESIGN STRESSES

where

f_1 = factor due to inherent variability in the species,

f_2 = actor due to long time. loading;

f_3 = factor due to accidental loading;

f_4 = factor for grade of the material;

f_5 = factor for location of use; and

f_6 = factors for specific design, such as form factor, etc.

3.3.2 It will be useful to understand the derivation of the above factors. But here it will be discussed briefly to make the reader understand the general methodology and concepts involved. It is known that the fundamental stresses all over the world, as explained earlier, are obtained from the test data of small clear specimen taken out of five to ten logs from each of the different localities where the species is grown. The tests are conducted and the average results are presented under a highly standardized procedure. From the study of variability, the standard deviation, and normality assumption of some species, particularly teak, a factor $f_1 = 0.72$ has been used to multiply the average modulus of rupture to get 95 percent confidence lower limit. Several other correction factors have been used for groups of species, or specific species, in other countries and attempts were made to obtain 99 percent confidence limits also. These statistical aspects are discussed in **3.4**.

3.3.3 As it is well known that under long time loading, wood exhibits creep depending on the applied stress, a factor $f_2 = 0.6$ had been taken based on earlier experiences in USA. However, some recent experiments at the Forest Research Institute, Dehra Dun, have indicated that a load equivalent to about 45 percent or below of the load at elastic limit (which itself is generally 60 percent of modulus of rupture) does not cause failure due to creep even for long periods. This can reduce this factor to 0.3 ($0.45 \times 0.6 = 0.3$), but no changes have yet been introduced as the final factors of safety are on the safer side and they are in use for a long time. In USA appropriate factors are specifically used for different duration of load, as also adopted in NBC (*see* Table 12).

TABLE 12 MODIFICATION FACTOR K_2 FOR CHANGE IN DURATION OF LOADING

DURATION OF LOADING	MODIFICATION FACTOR K_2
Continuous	1.0
Two months	1.15
Seven days	1.25
Wind and earthquake	1.33
Instantaneous or impact	2.00

3.3.4 As there is always a possibility of accidental over-loading a structure, inspite of all precautions, a factor of $f_3 = 0.6$ has been taken in earlier days based on the then experiences in other countries. In this connection it may be known that several recent investigations have revealed that ratio of fibre stress at elastic limit under dynamic condition to that under static condition is nearly 2.5, and that of dynamic modulus of elasticity to static modulus of elasticity is 1.5. Timber is well known for its capacity to show nearly double the strength under dynamic loads compared with that under static loads. Thus, there is hardly any justification for reducing fundamental stresses for sudden temporary over-loading which can never be twice the original static load; but as the over-loading, may also occur sometimes for long durations, this factor is necessary to be introduced for deriving the working stresses.

3.3.5 Taking the above three factors into consideration the factor-of-ignorance, presently used in this country works out to be

$$\left(\frac{1}{0.72} \times \frac{1}{0.6} \times \frac{1}{0.6}\right) = 3.86.$$

This is slightly higher than the factor used in other countries (3.37 in USA). Comparable 'basic stresses' between timbers of this country and other countries can be obtained only by dividing the fundamental stresses by the 'factor-of-ignorance' adopted in the respective countries.

3.3.6 In India, 3 grades of structural timbers are recognized on the basis of possible influence of defects on them. It is estimated that defects do not reduce the strength in Grade 1 by more than 12.5 percent, in Grade 2 by more than 25 percent and in Grade 3 by more than 37.5 percent (IS : 3629-1966). Accordingly factors of 0.875, 0.75, and 0.625 have been used for f_4 for respective grades. In Western countries the factor applied for the grade is sometimes known as 'strength-ratio' (ASTM-D.245) and these stresses are sometimes referred to as grade stresses. Thus the strength ratio denotes the ratio between basic stress and grade stress for a particular grade of timber. It is interesting to note that in this ratio there is an assumption that the factors $1/f_1$, $1/f_2$, $1/f_3$ leading to derivation of basic stresses have the same extent of influence in all grades. The present practices in other countries are that there are different grades for different species, and different end uses. Many trade associations dealing with particular species have put out different grades and also give out corresponding grade stresses. In India too with the changing economic pattern by using several secondary species, a need may arise for reconsideration of structural grades. In fact, in a seminar held in Dehra Dun (1976) for architects, builders and engineers dealing with timber structures, a suggestion was made to introduce a fourth grade consisting of some strong timbers which are generally and properly understood to be 'non-durable' and 'non-treatable', and which can be safely employed for temporary construction and service purposes. This suggestions is also included in IS : 3629-1966 for Class 3 durability and Class c treatibility.

3.3.7 As timber structures are likely to be located in different places ranging from extremely dry to extremely humid and wet situations, suitable factors for location of use are required to be considered for deriving safe working stresses.

By a series of observations at the Forest Research Institute, factors 1.0, 5/6 and 2/3 are used for f_5 for 'inside', 'outside' and 'wet' locations respectively; that is, for locations where timber will remain completely dry and protected like in the inside of a building, or subjected to alternate wetting and drying, or will remain more or less continuously in damp and wet conditions like being in touch with ground, in dockyards, in shores, etc. In Australia these factors are slightly different but in most other countries, this factor is not specifically considered but seems to be implied in the grade stress for different species which prescribe specific end uses under different circumstances.

3.3.8 In consideration of all the above, the present factor-of-safety applied to modulus of rupture as obtained in laboratory, works out like 5 (reciprocal of $0.259 \times 0.75 \times 1.0 = 0.19 \approx 0.2$) for inside locations, for grade 2. Similarly, factors of safety for other properties are also derived for the three locations for Grade 2, and given in Table 13. While these factors as such are applied directly to the fundamental stresses in case of bending, compression parallel to grain, and compression perpendicular to grain, it is not so in the case of shear. The fundamental shear values are increased by 10 percent and then divided by the respective factors indicated in Table 13, because the shear tests on small clear specimens are usually done on a corner notched specimen which gives a lower value. The shear strength in specimens without a notch is usually 5 to 15 percent (average 10 percent) higher than that in notched specimen for different species. It may be further noted that the factor of safety for shear values for all the different locations are retained same, as maximum shear occurs in neutral planes which is not so seriously affected as extreme fibres exposed under different locations.

3.3.9 From the above discussion and considerable amount of recent research publication, it seems there is sufficient justification for considering revision of factors of safety, and revision of working stresses for the different species or groups of species, particularly keeping in view: (a) the incoming of large number of secondary species for actual construction, (b) the technological developments in protection of Indian species which are much stronger than the species in other countries used under similar conditions, (c) the possibility of developing laminated structural elements by combination of inferier and superior species, (d) the utmost needed economy in timber utilization in India owing to serious depletion of forests, shortage of constructional timbers, and (e) improvements in economical designs of timber constructions.

3.4 Reliability of Data and Confidence Limits

3.4.1 When designing any structure on the basis of published data, it would be necessary for the engineer to know the origin and reliability of the data. Particularly in wood, which exhibits wide variation in strength on account of different factors, the strength data will be relevant and can command the required confidence only when such data is associated with a measure of variability which has now become possible owing to high degree of standardization in testing and evaluation. For reasons of economy and non-availability of full facilities, it may not always be possible for all laboratories to follow strictly all the relevant clauses of published standards, and in all such cases the data should be accompanied by comparison of standard data and relevant statistical discussions. These aspects are discussed below.

3.4.2 The first step for evaluation of properties of any material is the standard method employed for selection of the material. Different countries have adopted slightly different procedures for the same. Some countries which have their own timber resources have proceeded from selection of logs themselves of the required

TABLE 13 FACTORS OF SAFETY APPLIED TO FUNDAMENTAL STRESSES TO DERIVE SAFE WORKING STRESSES

(*Clause* 3.3.8)

Sl No.	Strength Property Working Stress	Standard Grade		
		Inside	Outside	Wet
(1)	(2)	(3)	(4)	(5)
i)	Extreme fibre stress in beams for non-coniferous species	5	6	7.5
ii)	Extreme fibre stress in beams for coniferous species	6	7	8.5
iii)	Shear along the grain	7	7	7
iv)	Horizontal shear in beams	10	10	10
v)	Maximum compressive stress parallel to grain	4	4.5	5.5
vi)	Compressive stress perpendicular to grain	1.75	2.25	2.75
vii)	Modulus of elasticity	1.25	1.75	2.0

species from different forest zones of their own country. Some countries, particularly timber importing countries, choose their testing sticks from converted material from depots. In India, based on long experience and also recent work developed at ISO level, the standard selection of the trees and logs for timber testing is governed by IS : 2455-1974 which lays down rules not only for selection of 10 model trees for marking, felling, and conversion of the same into suitable logs for their despatch to the testing authority with relevant documents but also for receipt and proper storage of the logs by testing authority, for marking and conversion of logs into sticks, and for storage of such sticks until tested. Rules have also been prescribed for the order of routine tests to be conducted for selection of test specimen from different matched sticks in green and dry condition. A schedule has also been prescribed for allotment of material from different bolts for different tests depending upon the relative importance of tests and the variation of the properties in question. Another standard IS : 8720-1978 covers sampling of scantlings from depots and their conversion for timber testing. It may be observed from the standards that the actual test specimens are comparatively small in size as compared to the bulk material and so representative portions of the bulk material are chosen for different tests. In selecting the bulk material itself methods of random sampling as recommended in IS : 4905-1968 are followed and all precautions are taken for establishing the absolute identity of the species. It is only under such detailed standardization procedures, the results of different species become well comparable.

3.4.3 The test specimen are then prepared and tested according to IS : 1708-1969 as already described under **3.1**. Where structural sizes are required, IS : 2408-1963 is followed. However, the presentation of data of physical and mechanical properties is in accordance with IS : 8745-1978 which prescribes details regarding taking averages, a scheme to round off the data under different tests, and recording all relevant information of the data which will help to assess reliability of the data.

3.4.3.1 In the presentation of data, the average of all sticks in a bolt (known as 'tree average', if from logs) or in a scantling (known as 'scantling average', if from converted timber in a depot) are first evaluated. Then the average of such averages are reported as species averages of a given locality. Sometimes when the same species is tested from different localities and there is no significant difference in the average figures, the averages of localities are averaged to get an 'all-India' average of the same species.

3.4.3.2 The tree average in dry conditions (or scantling average as the case may be) is adjusted to 12 percent moisture content by the formula:

$$\frac{S_{12}}{S_g} = \left(\frac{S_d}{S_g}\right)^{f-12/f-d}$$

or $$\frac{f-12}{f-d} = \frac{\log S_{12} - \log S_g}{\log S_d - \log S_g}$$

where

S_{12} = strength required at 12 percent moisture content,

S_d = strength observed at d percent moisture content below the fsp,

f = fibre saturation point (fsp.),

S_g = strength in green condition, and

d = observed moisture content in dry condition.

If the fibre saturation point is not available then the formula employed is:

$$\left(\frac{S_{12}}{d}\right) = \left(\frac{S_d}{12}\right)$$

provided the difference between 12 and d is not greater than 5.

3.4.3.3 When data in different conditions (say, green and dry condition) is required to be compared, care is taken to see that the data corresponds to equal numbers of matched samples in each condition. Otherwise the data is adjusted by giving due weightage to the number of samples tested and by evaluating the average ratio of the values in the condition from known matched materials explained below :

If (a) Species average of 5 bolts in green condition = K; and

(b) Tree average of five individual bolts in the green condition are given by S_1, S_2, S_3, S_4, and S_5, and only values of 3 matched bolts in dry condition are known as S'_1, S'_2 and S'_3 then, the species average K', in the dry condition for all five bolts is given by :

$$K' = K \times \frac{1}{3}\sum_{n=1}^{3}\frac{S'_n}{S_n}$$

3.4.3.4 Among the important characteristics and properties generally reported the following also are reported so that ideas can be developed on variability of the strength in green and dry conditions of the species and their reliability for comparison can be judged.

a) An 'improvement factor' which is the average percentage of improvement of strength values from green to dry condition (at 12 percent);

b) Details of area of growth, rate of growth and dimensions of bulk material (logs or scantlings);

c) Number of trees, logs, or scantlings, and number of specimens for individual tests as the case may be; and

d) Measure of variability is described in Table 4 of IS : 3745-1978. In brief these include, as necessary, the range of observations (that is, maximum and minimum values of all observations in a test); the standard deviation σ or co-officient of variation $\sigma/\bar{x}$ to be calculated according to number of logs or scantlings and number of localities chosen, etc. For calculating σ and $\bar{x}$, *see* **3.4.5.1**.

3.4.4 As stated in **3.4.3.4**, in India, greatest reliability has been placed on average values, that is, arithmatic mean of different values as obtained from standard test data of representative specimen. However, in deriving working stresses, as already explained in **3.3**, the values of standard deviation of teak (representing the average of all wood species) is taken into consideration for working the various factors of (ignorance) safety. Recently it has been established that variation between trees is more than variation within a tree. Coefficients of variation for different properties of timber based on average values for 50 green consignments of species, each based on five trees from a locality, are given in Table 14. From this it is apparent that with an average coefficient of variation of 11.5 for the different properties, the data that was being collected previously on the basis of 5 trees is fairly justifiable and the present standard prescribing 10 trees is amply justified.

TABLE 14 COEFFICIENT OF VARIATION FOR DIFFERENT PROPERTIES OF TIMBER

Property	Coefficient of Variation		
	Average	Minimum	Maximum
(1)	(2)	(3)	(4)
Specific gravity (vol. green)	5.2	0.6	12.7
Specific gravity (vol. oven dry)	6.0	1.5	11.9
Shrinkage			
Radial	12.0	2.6	26.3
Tangential	9.2	3.7	22.5
Volumetric	8.0	2.6	21.2
Static Bending			
Fibre stress at elastic limit	10.4	3.6	27.5
Modulus of rupture	7.8	3.0	22.7
Modulus of elasticity	10.5	2.7	31.8
Work to elastic limit	16.6	3.9	42.6
Work to maximum load	16.0	5.8	29.4
Total work	18.7	4.5	71.7
Impect Bending			
Fibre stress at elastic limit	8.7	3.3	23.2
Maximum height of drop of hammer for complete flaiture	12.0	2.9	32.0
Modulus of elasticity	12.3	3.3	33.4
Work to elastic limit	9.4	2.4	18.6
Brittleness (izod)	19.0	4.3	38.2
Compression Parallel to Grain			
Fibre stress at elastic limit	12.9	4.2	37.9
Maximum crushing	9.4	2.4	22.9
Modulus of elasticity	12.3	2.3	31.5
Compression Perpendicular to Grain			
Fibre stress elastic limit	14.4	5.4	31.8
Hardness			
Radial	12.3	3.1	24.5
Tangential	11.6	4.5	29.5
End	10.7	3.4	23.7
Shear			
Radial	10.6	3.3	21.1
Tangential	10.4	1.8	20.2
Tension Perpendicular to Grain			
Radial	17.0	2.9	44.4
Tangential	15.8	5.5	35.1
Fibre Saturation Point (Y_o)	4.0	1.1	9.0
Average	11.5	3.2	28.7

3.4.5 The practices for reliability of data in other countries are slightly different and vary according to a required level of probability. They are briefly discussed below.

3.4.5.1 In UK and some other countries the basic stresses (that is, the stress which can be safely and permanently sustained by timber containing no strength reducing features) are derived from tests on small clear specimen as discussed in 3.3.1(b). In deriving these stresses, a histogram or normality curve (Gaussian distribution curve) of all values obtained from a large number of specimen, is first drawn. The standard deviation is then evaluated by the formula:

$$\sigma = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n}}$$

where

σ = standard deviation,

x = individual test result,

$\bar{x}$ = average of all test results (mean), and

n = number of specimens tested.

From this the basic stress is derived by the formula:

$$f_b = \frac{f_m - P\sigma}{R}$$

where

f_b = basic stress,

f_m = mean value of the stress as determined under tests ($\bar{x}$),

R = reduction factor which is a factor allowed for small variations in moisture content, duration of test loading, size and shape of specimen and so naturally varies according to the nature of stress (R = 2.25 for bending, tension and shear; 1.4 for compression parallel to grain; and 1.2 for compression perpendicular to grain), and

P = probability coefficient (1.96 for 1 in 40; 2.0 for 1 in 44 and 2.33 for 1 in 100 which indicate the probable values falling below the level).

For bending, shear, tension and compression parallel to grain, the lower 1 percent exclusion limit of probability level is considered by taking P as 2.33. For compression perpendicular to grain lower than 1 in 40 probability level is considered by taking the value of 1.96.

3.4.5.2 While in India sometimes a factor of safety is applied to modulus of elasticity (*see* **3.3.8**) no such factor is applied in UK and some other countries for calculation of deflection. Hence there is no such property as basic stress discussed above for the modulus of elasticity. However, design considerations in those countries lead to the use of a mean value E_m and also a statistical minimum values E_N depending on whether one or more members act, to share the load. Taking 1 in 100 probability level, when one member acts alone, the above minimum value $E_n = E_1$ and this is usually recorded in standard data, and design codes of these countries. Thus

$$E_1 = E_m - 2.33\sigma$$

where σ is the standard deviation. When more than one member takes the load, it is considered reasonable to design using increased minimum value, and the formula below is used to obtain the statistical minimum value:

$$E_N = E_m - 2.33\sigma_N$$

where σ_N is standard deivation for multiple pieces in each component and is equal to

$\sigma/\sqrt{N}$ where

N represents the number of pieces sharing the load.

Hence, $E_N = E_m - 2.33\ \sigma/\sqrt{N}$

When $N = 1$ in the above equation, E_N becomes equal to E_1 which is the recorded modulus of elasticity in standard data. As N increases, E_N approaches E_m and so the design codes of these countries permit the use of E_m when four or more members act together to support a common load. From the above discussion it can be seen that:

$$\sigma = \frac{E_m - E_1}{2.33}$$

$$\text{or } E_N = E_m - \frac{E_m - E_1}{\sqrt{N}}$$

Similarly

$$\frac{E_N}{E_1} = \frac{E_m - 2.33\ \sigma/\sqrt{N}}{E_m - 2.33\ \sigma}$$

On the same principle, the other stresses are also computed sometimes for improving the design considerations, that is, if f stands for the relevant stress, and using the same notation as above

$$\frac{f_N}{f_1} = \frac{f_m - 2.33\ \sigma/\sqrt{N}}{f_m - 2.33\ \sigma}$$

4. TIMBER PROCESSING TECHNIQUES

4.1 Introduction — As discussed earlier, all timber is initially obtained from trees in forests and other areas, and before it is actually put into final use, there are several processes it has to undergo. The engineer should be familiar with these so as to understand not only the problems and costs involved in such processes but also to assess the adequacy and quality of the processing, so that the material that is being used is safe for structural purposes. There have been quite a number of instances in this country when well designed wood structures have given way because of inadequacy of processing required before final use. Hence brief mention is made here of various processes involved for converting wood from log form to its ultimately utilizable form, bringing out more prominently the aspects where some Indian Standards are available. It is not the intention to describe in very detail either the types of equipment and their maintenance or the methods and principles of processing techniques, or the details of layouts, costs, storage and movement operations under different processes. For these, adequate books and other literature are available, and some of these have been referred in Appendix B. An understanding of the above is required for regular processing engineers and technicians. But from the point of view of a constructional engineer, it would be sufficient to know the general outlines involved in various processes.

4.2 Log Storage and Conversion

4.2.1 When logs are harvested and transported usually proper precautions are taken to prevent any splits and decay. But before they are converted into beams, planks and scantlings, they require to be stored properly to avoid end drying and splitting. Such rapid end drying may result in considerable wastage of the material. One of the best methods of storing the logs is to debark them and keep them completely immersed under water for which most of the saw mills either construct special log ponds as necessary, or use nearby natural ponds, if any. In these ponds it would be often necessary to remove the contamination and keep the water clean to be free from bacteria and fungus. In the specially built ponds arrangements are generally made for frequent change of water. Where the facilities of log ponds are not available, the debarked logs are also stored on concrete floors under water sprays which can be either continuous or intermittant and recycled for economy. In the absence of water-spray facilities, logs are required to be stacked on raised platforms under shade. The bark is usually removed except in cases where the species is prone to heavy surface cracking. A suitable prophilactic treatment, as recommended in IS : 401-1982, should be given to the logs in stacks. In IS : 1141-1973, some end-coating compositions have been recommended which can also be adopted for logs stored in open yards depending on local circumstances. Out of the many end coatings tried at the FRI, the paraffin and its emulsion, bitumen solution and asbestos powder, bitumen solution coating followed by aluminium paint, bitumen solution and red lead, were rated high in effectiveness.

4.2.2 In further conversion of logs to smaller sections, most of the mills have two distinct operations: (a) log breaking, and (b) resawing. The former is carried on heavy type machinery which can take the bulky logs. The logs are first cross cut to the required lengths, and then the edges (or slabs) are removed in band mills, or big circular saws or sometimes even by hand sawing where no facilities of machines are available. Then the required sizes of 'beams' and 'planks', are obtained by further cutting on the same or similar machines. Depending on the space and quantity of production in the mill, there are a variety of machines to choose for 'breaking' the logs, that is, converting the logs vertically along the grain. Under this operation, usually section of 15 cm and above, sides or planks not less than 2 cm thick, and of width covering the full section of the log are taken out. After completing the log breaking operations, the material is 'reconverted' (also known as 're-sawn') by means of several types of 're-sawing' machines which are smaller band-saws of about 5 cm width or smaller circular saws of about 45 cm diameter (also known as ripping saws). This operation is also known as 'edging'. The material is then cross cut again (also known as trimming) to the required length sizes. Where machines are not available resawing is done by hands in various ways. In this connection a reference may be made to IS : 4423-1967. All the wastage, like off-cuts, saw-dust, trimmings, etc, are transported towards one end, and all the finally converted material is transported to the other end for inspection and grading. One of the important objectives of saw mill and conversion operation is not only to avoid wastage and obtain the required size of the material but also plan operations in such a way that objectionable defects in timber are carefully removed and improve the grade of the turned out material, and thus obtain better value for the converted material. For this, not only the machine precision and skills must be high but also the operational discretions must be carefully used. The standard preferred cut sizes of structural timber are discussed in **2.5.2**.

4.2.3 After the mill operations and grading, the material is either sent to seasoning kilns or air-drying sheds for reducing the moisture content. Then it is sent to preservation plants for necessary treatment, if any, in case it is to be used as such. Otherwise, it is first sent to wood workshops for other wood working operations, such as planning, tongue and grooving, tennoning, mortising, and boring before applying preservative treatments. Where production is not high, these operations are also done by hand tools.

4.3 Timber Seasoning

4.3.1 Seasoning essentially means removal of excess moisture from wood and bringing it to the level of equilibrium with the humidity in the atmosphere in which wood is to be used. IS : 287-1973 prescribes different permissible moisture content for different zones of India for different end uses of wood. Quite often construction engineers have been found to confuse seasoning as a process which would render some unknown improved qualities to the material such as durability or strength. This is quite erroneous. In the removal of excess moisture from wood, seasoning no doubt helps to reduce otherwise considerable losses of wood due to surface cracking and spliting. The strength of wood no doubt depends on moisture content (*see* **3.2.3**). In the several techniques employed in seasoning, the comparative aim is to remove the excess moisture in the shortest time possible and with the least amount of degrade so that the technique employed is as cheap as possible, and as convenient as possible, to to local circumstances. During the removal of excess moisture, wood shrinks, and if shrinkage is not uniform and not appropriately controlled, differential stresses may be set in the material causing sometimes splitting, warping and degrade in the stock of timber. The rate of drying of wood, and consequently the shrinkage is governed by interaction of three external conditions surrounding the material. They are: (a) temperature which will start drying the wood from the surface, (b) circulation of air, which will carry away the moisture evaporated from the surface of wood, and (c) relative humidity which will control the rate of outward diffusion of moisture from the interior of the wood to its surface. These factors naturally depend on the species of wood in question and how refractory they are to seasoning (*see* **2.3.10**). The important techniques, of seasoning relevant to structural timbers and their limitation are briefly described in the paragraphs which follow. For greater details on operation controls, details of kiln design, etc, reference should be made to the numerous text books and other literature on Indian woods which had mainly emanated from the Forest Research Institute, Dehra Dun. Some of these have been referred in Appendix B. There are special seasoning methods for other purposes such as high temperature drying, chemical seasoning, solvent seasoning, high frequency drying, vapour drying, vacuum drying and boiling in oil, which have not yet attained any commercial popularity nor they are of specific interest for structural purposes. Hence they have not been discussed here in detail.

4.3.2. *Air-seasoning* — Under this method the sawn timber is properly stacked with the help of crossers on raised foundations in open air at a clean and dry place. In air-seasoning, proper stacking is the most important, and the location of stack and its orientation with reference to air movement and direct heat of the sun is equally important. Experience will indicate how these are to be adjusted so that undue degrade is not developed in the stack. However, some precautions indicated below will help proper air-seasoning. The width of the individual stack should not ordinarily exceed about 1.5 to 2 metres. The longest planks or scantlings should be placed at the bottom and the smaller ones at the top. The crossers should be of strong timber and uniform thickness. They should be vertically aligned one above the other and heavier beams should be placed at the top so that undue warping of members is prevented. Heavy sections like railway sleepers and thick beams can be stacked in crib forms using the same members as crossers where necessary. The stack should be well protected from direct sunlight and heat, and too rapid winds. The ends of members may be coated wherever necessary. Where a number of stacks are necessary and large amount of timber is required to be air-seasoned special sheds may be constructed as required. Air-seasoning is necessary and economically useful for seasoning all sections above 10 cm thickness. The initial and final moisture content of members in the stack may be determined by marked samples placed at different places in the stack. Final moisture content may also be determined by calibrated moisture meters.

4.3.3 *Kiln-seasoning* — In this process the seasoning is obtained by drying timber in specially designed kilns in which the temperature, humidity and circulation of air can be controlled better than in air-seasoning. Any limitations placed by air-seasoning due to uncontrollable factors can be overcome in this process, and so the period of seasoning will be considerably shortened for the same species and sections. There are several methods of introducing the heat, etc, in the kilns, but the most popular in the country seems to be the one steam-heated with overhead internal fan and reversible air circulation systems. Perforated steam tubes are used for controlling humidity also. The kiln is initially set with high humidity, low temperature, and gradually altered to low humidity and high temperature with controlled and reversed air circulation in order to reduce the moisture content from green condition to about 12-15 percent, which is required for actual use. The kilns are also provided with appropriate vents and ducts. All types of species up to 5 cm thick, can be properly seasoned in such cases. Thicker sections, that is, above 5 cm and up to 10 cm must be initially air-seasoned up to about 25 percent before kiln-seasoning for economic reasons. Forest Research Institute has published different schedules of seasoning for different species, and these have been standardized and given in IS : 1141-1973. In the end, the same kilns are also used for what is called 'conditioning' of timber to relieve edge-hardening stresses, if any, have been developed in the material. The most common size of an ordinary kiln is to take a charge of about 14 to 15 cubic metres. In the recent years the cost of construction of such a kiln with a suitable boiler has roughly worked out to be between Rs. 50 000 and Rs. 60 000. Some ready-made commercial seasoning kilns with a few sophisticated controls are available in the market for slightly higher price. The cost of seasoning of average species and average dimensions roughly works out to be Rs. 50 to Rs. 70 per cubic metre.

4.3.4 *Solar Kiln Drying* — The installation of full scale economic seasoning kiln as described above needs high initial investments. There are already quite a few of such kilns existing in different parts of the country, either as part of big saw mills or even as independent units. Some types of low cost seasoning kilns also have been developed like furnace heated kilns, etc. But recently a kiln designed to trap solar energy wherever possible as heating agent and eliminating a separate boiler has become fairly popular and useful. Utilizing transparent screens which permit transmission of short-wave solar radiation reaching black surfaces inside the kiln, and which also prevent going out of long wave emission from these black surfaces, it has been possible to trap large quantities of heat of low temperature, that, is up to 60°C and obtain fairly quick drying of timber. Although the heat is easily obtained from the sun, the electric energy is still required for running fans to control air circulation. The kilns may be provided with vents, ducts and humidifying arrangements also. It has been observed that the efficiency of solar kilns is between that of air-seasoning and kiln seasoning described above. The air-seasoning periods are claimed to have been reduced by about 60 percent. Some efforts are under way to find whether control of humidity and air circulation can also be obtained without the use of external electricity.

4.3.5 *Determination of Moisture Content* – This is a very important link in timber seasoning and utilization. For accurate determination of moisture content of the stack, small moisture discs are taken out from sample pieces placed in different locations in the stack. These are initially weighed, oven-dried for about 24-48 hours, and reweighed (*see* IS : 1708-1969). The moisture content of the disc, and so of the sample in question is given by

$$\text{moisture content} = \frac{(\text{initial weight of the disc} - \text{oven dry weight of the disc}) \times 100}{\text{oven dry weight of the disc}}$$

Periodic weightment of the sample would then indicate the moisture in the sample. Average moisture content of all samples in the stack is taken as moisture content of all timber in the stack. However, as this is a destructive and time consuming method, various types of electrical moisture meters have come into vogue. These depend mostly on resistance (and sometimes on capacitance) offered by wood under different moisture contents between its fibre saturation point and dry condition. They naturally depend on species, the type of electrode probes driven in wood, the extractives in wood, etc. Hence, they require to be properly calibrated and some guidance to this effect is also available in IS : 1141-1973.

4.4 Timber Preservation

4.4.1 One of the most common fears which prevents use of wood for structural purposes is its deterioration or degradation, which may be due to biological or even other causes. For this reason, whenever timber had to be used, engineers always used to prefer only long established very durable timbers like teak. However, in the present day the science of wood perservation by chemicals has advanced so much that many types of hitherto unknown secondary species have begun to be used after treatment, with the same confidence as the popular species were being used earlier. Also the various timber species have been classified into different durability classes (*see* **2.3.8**) and the methods of treatment of these species have been standardized (*see* IS : 401-1982). Consequently the choice of timber for structural propose has become somewhat easier wherever treatment facilities exist or can be created as required.

4.4.2 The main cause of decay or degrade which necessitates wood to be chemically treated is biological, which may be caused due to some types of wood-destroying fungii or insects. The term 'decay' and also 'rot' is generally used for the destruction caused due to fungii which feed on the principal constituents of wood, namely, cellulose in lignin [*see* **2.4.7**(b) and **2.4.7**(j)]. The terms white rot, brown rot, incipient decay and sepstain as explained earlier describe the decay. Decay due to fungii usually occurs only when temperature is between 20° and 35°C, moisture between 20 and 50 percent when there is adequate supply of oxygen, and pH between 4 and 5. The insects which attack timber are popularly known as 'bees', 'beetles', 'borers', 'pin-hole borers' and 'termites' which have some characteristic habits of attacking barks, or green wood, or fermenting wood, etc. Some of them feed on fungus which is cultivated on wood. Some of them (powderpost beetles) attack ring porous hard woods as the large diameters of the pores are suitably adopted for laying the eggs by female insects. Thus, softwoods adopted for laying the eggs by female insects. Thus, softwoods are somewhat immune to such beetles. A detailed note on termites is given in IS : 6313-(Part 1)-1971. There are about seventy species of termites which can be grouped into two broad classes: (a) the subterranean termites, and (b) drywood termites. The former are more dangerous and their attack is by boring holes longitudinally inside the timber which may not be easily observed from outside. The latter generally bore across the growth rings and can be easily detected. In view of these known behaviour of fungii and insects, if buildings are properly designed and constructional provisions are suitably made to prevent attack by fungii and insects, the dangers of degrade in constructional wood can be largely eliminated. As a further protection, chemical treatment of material as briefly described in the following clauses would ensure safety of construction beyond doubts.

4.4.3 *Wood Preservatives* — IS : 401-1982 covers all types of preservatives, their description, choice and methods of treatment for different species and different purposes besides other useful information on the subject of wood preservation. There are principally three types of preservatives : (a) oil type, (b) organic solvent type, and (c) water soluble type, which are again divided into two sub-classes as: (1) leachable types and (2) fixed (or non-leachable) type.

4.4.3.1 The oil type preservatives are coal tar creosote with or without admixture of petroleum coal tar, fuel oil or other oils having high boiling range. These are recommended for exterior use only, they are extremely stable and possess high toxicity to all organisms and non-corrosive to metals. The wood is, however, discoloured and gives some unpleasent odours due to treatment. The creosote for wood preservation should conform to IS : 218-1961 and fuel oil (LV grade) to IS : 1593-1960. The oily nature of wood is a protection against splitting and does not permit any painting on wood. Fifty percent admixture of fuel oil, etc, with 50 percent creosote ensures prevention of evaporation or leaching of creosote from treated material.

4.4.3.2 The organic solvent type preservatives are used after dissolving the toxic chemicals in suitable organic solvents. The treated wood is clean, and it can also be painted. Some water repellent compounds like wax can also be added to the preservatives. The various preservations are:

a) copper and zinc naphthanates (*see* IS : 1078-1973) which are metallic salts of imported naphthenic acid. Recently Forest Research Institute has developed similar wood preservatives from copper, zinc and chir-pine resins from indigenous sources which are claimed to be equally effective.

b) pentachlorophenol (PCP), a fully chlorinated derivative of phenol (IS : 716-1970) and is indigenously manufactured by Durgapur Chemical Works, Durgapur.

c) benzene hexachloride (BHC) conforming to IS : 560-1980.

d) DDT conforming to IS : 563-1973 (dichloro diphenyl trichloro ethane).

4.4.3.3 Water soluble type preservatives are inorganic salts soluble in water. However they get leached out due to action of water but it can be prevented to some extent if weatherproof paints are coated on the treated material. They are quite useful under cover. The various salts are:

a) *Zinc chloride* — Toxic to fungii and borers but not so for termites. It has some fire-retardant chracteristics also but tends to be hygroscopic.

b) *Boric acid and borax* — Useful against borers, sapstain and some types of termites. It has good penetrating properties and so is usually used for veneers and thin members.

c) *Sodium pentachlorophenate (Na-PCP)* — Highly effective against sapstain.

d) *DDT and benzene hexachloride (IS : 562-1978)* — Water dispersible powder useful for spray as a prophilactic treatment against borers.

4.4.3.4 Water-soluble fixed type preservatives consists of mixtures of various salts described above with the addition of a fixative salt, usually sodium dichromate or potassium dichromate. In presence of wood, they react and form non-leachable complex salts permanently fixed inside timber. Hence they can be used in outside locations also. Treated timber should, however, be allowed to dry for a period of 3 to 6 weeks to complete the fixation process. These preservatives are applied at room temperatures only, and treated wood can be easily painted or polished or waxed. If proper care is not taken, treatment with water soluble preservatives may develop small cracks. The various chemicals are described below briefly:

a) Copper-chrome-arsenic composition (CCA) consisting of copper sulphate, sodium or potassium dichromate and arsenic pentoxide in approximate proportion of 7 : 10 : 2 by weight (Total solid content 95 percent). IS : 10013 (Part 2)-1981 prescribes the following proportions:

	Normal	*Minimum*
Copper sulphate	37.5	35
Sodium or potassium dichromate	50.0	47.5
Arsenic pentoxide	12.5	10.0
Total	100.0	92.5

b) Acid-cupric-chrome composition (ACC) consisting of copper sulphate, sodium or potassium dichromate and chromic acetate in approximate proportion of 10 : 9 : 1 by weight (total solid content 95 percent) and pH between 2.7 and 4.2. IS : 10013(Part 2)-1981 prescribes the following proportions:

	Normal	*Minimum*
Copper sulphate	50	47.50
Sodium or potassium dichromate	45	42.50
Chromic acetate	5	4.75
Total	100.0	94.75

c) Copper-chrome-boric composition (CCB) consisting of copper sulphate, boric acid and sodium or potassium dichromate in the proportion of 6 : 3 : 8 (*see* Appendix B) or 10 : 1 : 10 (as recommended in IS : 401-1982). IS : 10013 (Part 2)-1981 gives the following proportions:

	Normal	*Minimum*
Copper sulphate	35.0	32.5
Boric acid	18.0	15.5
Sodium or potassium dichromate	47.0	44.5
Total	100.0	92.5

This is an alround and all purpose preservative including conditions of soft rot attack.

d) Chromated zinc chloride (CZC) consisting of zinc chloride and sodium or potassium dichromate in the ratio of 81.5 : 18.5.

e) Zinc meta-arsenite consisting of zinc oxide and arsenic trioxide in the proportion of 2 : 3 with acetic acid sufficient to keep the compound in solution under operating conditions.

f) Zinc chromo-boric composition of zinc chloride, sodium or potassium dichromate and boric acid in proportion of 3 : 4 : 1.

4.4.3.5 Of all the above, the most commonly used wood preservatives for treatment of building timbers are creosote, pentachlorophenol, CCA, CCB, ACC, boric acid and borax compositions. These compounds under different trade names, such as tanalith, celcure, boliden salts and compounds of boron, tin, etc, are used in other countries. In India also 'ASCU' (conforming to CCA and CCB compositions) 'Solignum' (creosote or petroleum based, PCP containing, resinous substances), etc, are used. In any case when a new commercial product becomes available in the market, it would be best to obtain the efficacy of such preservatives from recognized wood preservation laboratories and also obtain indication of chemical constituents and, if possible, their proportions to be sure of the performance of such preservatives under different conditions. IS : 4873-1966 describes the method for the laboratory testing of wood preservatives against fungii by soil block method and Kolle flask methods. IS : 6341-1971 describes method of laboratory tests for efficiency of wood preservatives against soft-rot which is found in very damp pieces. IS : 6497-1972 prescribes methods of test for the efficacy of preservatives and also for evaluating the natural durability of timber used in cooling towers. Similarly IS : 6791-1973 describes methods of testing natural durability of timber and efficacy of wood preservatives against marine borers.

4.4.4 The methods of tretment and degree of preservation, that is, the absorption and penetration of preservatives would naturally depend upon the different hazards and so the protection required, and to keep it economical and safeguard subsequent maintenance costs. IS : 401-1982 gives exhaustively the recommended processes of treatments, recommended preservatives, ranges of absorption for different situations. Several publications of the Forest Research Institute, Dehra Dun, have also brought out these very elaborately. A summary of the necessary information, useful for structural engineers is given in Table 15 to serve as a ready reference and rough guide. The various methods of treatment commonly employed are described and can be broadly classified as: (a) pressure methods, and (b) non-pressure methods. However, before treatment the material is brought to appropriate moisture level, surface is well cleaned and properly stacked. Where necessary, the material is steamed and vacuumed to kill any infection, reduce the moisture and also facilitate easy penetration of preservatives during subsequent treatments.

4.4.4.1 In the pressure method, inpregnation of wood by preservatives is obtained in cylinders equipped with vacuum pressure pumps, storage and mixing tanks. For treatment with creosote, such cylinders and tanks are also equipped with steam heating coils. The details of pressure treatment plant are given in IS : 2683-1980. In the full-cell process which is generally used for species difficult to treat and for high preservative loading, an initial vacuum of about 56 cm is given for about half-an-hour. This is followed by filling the cylinder with preservatives and building a pressure of 2.0 to 12.5 kg/cm^2. For most of building components, the main aim being to get adequate absorption and penetration, the empty-cell process is employed for which no initial vacuum is necessary. The duration of pressure depends upon the species, the required loading, and the dimensions of timber inside the cylinders. After the pressure period, a vacuum is given for about fifteen minutes to recover any extra preservative adhering to surface layers of wood. Pressure cylinders are indigenously manufactured and there are about 200 plants distributed all over India. Some mobile plants have now come into vogue and these can be used in remote areas also and at erection sites of timber structures.

4.4.4.2 Under the non-pressure treating methods, the following may be of some interest for structural timbers.

a) Surface applications either by brushing or spraying or dipping. For water soluble type preservatives, the moisture content of the wood can be around 20 to 30 percent. For dipping in organic solvent type or oil type preservatives, the moisture content should be around 15 percent. Surface applications do not give long protections and is useful only for re-treatment of cut surfaces or for some temporary treatments at sites. This treatment should be repeated periodically for effective protection.

b) Diffusion treatment is applicable to green timber for treatment with water-soluble preservatives. The penetration of the preservative is achieved because of concentration gradients existing between preservative solution and free water present in wood cells. Sometimes the green material is first steamed for two to three hours after which the material is transferred to preservative solution at ambient temperature (known as quenching).

TABLE 15 RECOMMENDED PRACTICE FOR PRESERVATION OF TIMBER

(*Clause* 4.4.4)

GROUP	SERVICE CONDITION OF TREATED TIMBER	COMMODITY	PROCESS OF TREATMENT	PRESERVATIVE (*see also* 3)	RECOMMENDED ABSORPTION kg r	REMARKS
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Timber in direct contact with ground or water especially in outside location.	Sleeper (other than railway sleepers)	Hot and cold process (if applicable), diffusion treatment of green timber and pressure processes (preferably)	a) CTC LTC wit fuel oil (50 : 50)	80-128	For timber under a, b and c categories of treatability
					30-45	For timber under d and e categories of treatability
				b) CTC/LTC	64	For a, b and c categories of treatability
					25	For d and e categories of treatability
				c) CTC-fuel oil (25 : 75) + 2.5 percent PCP	80	For a, b and c categories of treatability
					30	For d and e categories of treatability
				d) CCA followed by 10 percent asphalt in crude oil after drying	10	For a, b and c categories of treatability
					5	for d and e categories of treatability
				e) ACC followed by 10 percent asphalt in crude oil after drying	10	For a, b and c categories of treatability
					5	For d and e categories of treatability
		Poles, fence posts, bridge timbers, box columns, sign boards, shuttering, etc	Hot and cold process (if applicable), Boucherie treatment for green poles and fence posts, diffusion treatment of green timber and pressure process (preferably)	a) CTC LTC with fuel oil (50 : 50)	160	
				b) CTC LTC	128	
				c) PCP	8	
				d) CCA	12	
				e) ACC	12	
				f) CCB	16	
		Marine timbers a) Timbers in contact with sea water, such as floating fenders, catamarans, piles, etc	Hot and cold process (if applicable), Boucherie treatment for green poles and fence posts, diffusion treatment of green timber and pressure processes (preferably)	a) CTC LTC with coal tar (60 : 40)	320	First coal tar shall be melted and only then creosote shall be mixed with it
				b) CTC LTC—fuel oil (50 : 50)	320	
				c) CCA	16-32	(Trials were carried out with 80-120 grade coal tar only)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
		b) Structures out of water but subject to tide, salt water splashes, etc	Hot and cold process (if applicable), Boucherie treatment for green poles and fence posts, diffusion treatment of green timber and pressure processes (preferably)	a) CTC LTC with fuel oil (50 : 50)	160	
				b) CCA	12	
				c) ACC	12	
				d) CCB	16	
		Timbers in cooling towers a) Constructional members		a) CTC LTC with fuel oil (50 . 50)	128	
				b) CCA	12	
				c) ACC	12	
				d) CCB	16	
		Timber in fill	Hot and cold process (if applicable), diffusion treatment of green timber and pressure processes (preferably)	a) CTC LTC with fuel oil (50 : 50)	160	
				b) CCA	16	
				c) ACC	16	
				d) CCB	20	
		Mine timbers a) Tramline sleepers	do	a) CTC LTC with fuel oil (50 : 50)	160	
				b) CCA	12	
				c) ACC	12	
				d) CCB	16	
		b) Pit props	do	a) CCA	8-12	If timbers become unserviceable due to mechanical failure or are to be left in mine for safety reasons, minimum retention may be used
				b) ACC	8-12	
				c) CCB	12-16	
2	Timber not in direct contact with ground or water but exposed	~~Bridge timber~~, shingles scaffoldings, ladders, etc	do	a) CTC LTC with fuel oil (50 : 50)	80	
				b) CCA	8	
				c) ACC	8	
				d) CCB	10	
				e) PCP	6.5	
3	Timber not in direct contact with ground or water but exposed and in addition given a cast of paint or varnish regularly after preservative treatment	Weather boards, fence rails, exterior doors windows, etc	Hot and cold process (if applicable), diffusion treatment of green timber and pressure processes (preferably)	a) CCA	6.5	
				b) ACC	6.5	
				c) CCB	8	
				d) PCP	5	
				e) CZC	16	
				f) Copper naphthenate	0.5	Calculated as copper
				g) Zinc naphthenate	0.8	Calculated as zinc
				h) Copper abietate	0.5	Calculated as copper

(Continued)

TABLE 15 RECOMMENDED PRACTICE FOR PRESERVATION OF TIMBER

(*Clause* 4.4.4)

GROUP	SERVICE CONDITION OF TREATED TIMBER	COMMODITY	PROCESS OF TREATMENT	PRESERVATIVE (*see also* 3)	RECOMMENDED ABSORPTION kg/m^3	REMARKS
(1)	(2)	(3)	(4)	(5)	(6)	(7)
4	Building timber for internal use but in contact with ground, soil or under humid conditions	Doors, windows, frames, leaves, ceilings, trusses, timber columns, pole support, etc	Hot and cold process (if applicable), diffusion treatment of green timber and pressure processes (preferably)	a) CTC LTC	80	
				b) CCA	6.5	
				c) ACC	6.5	
				d) CCB	10	
				e) CZC	16	
				f) PCP	5	
				g) Copper naphthenate abietate	0.5	Calculated as copper
				h) Zinc naphthenate abietate	0.8	Calculated as zinc
				j) Boric acid : borax (1 : 1)	6.5	
5	Building timber or timbers in interior use not in contact with ground or soil and used in dry conditions	a) Doors, windows, frames, leaves, false-ceiling purlins, pelmet, etc	do	a) CTC LTC	80	
				b) CCA	4	
				c) ACC	4	
				d) CCB	6.5	
				e) CZC	6.5	
				f) Copper naphthenate abietate	0.4	Calculated as copper
				g) Zinc naphthenate abietate	0.6	Calculated as zinc
				h) PCP	5	
				j) Boric acid : borax (1 : 1)	5	
		b) Furniture, cupboard, chicks, etc	Two liberal brush coats or momentary dipping	a) PCP 5%	—	
				b) Boric-acid : borax (1 : 1) 2% solution in water		
6	Timber for packing cases to be stored outside and exposed	Packing cases, pallets, ammunition boxes, cable drums, etc	Hot and cold pressure processes	a) *CCA	4	
				b) ACC	4	
				c) CCB	6.5	
				d) PCP	4	
				e) Copper naphthenate abietate	0.5	
				f) Zinc naphthenate abietate	0.8	
7	Timber for packing cases to be stored inside or under cover	do	Brushing spraying dipping	a) *CCA	3.2	
				b) ACC	3.2	
				c) CCB	4	
				d) PCP	4	
				e) Boric acid : borax (1 : 1)	3	
				f) Zinc-meta-arsenite	5	
				g) Copper naphthenate abietate	0.4	Calculated as copper
				h) Zinc naphthenate abietate	0.6	Calculated as zinc

(1)	(2)	(3)	(4)	(5)	(6)	(7)
8	Seasoned timbers and finished articles to be painted and used	Tool handles baskets ploughs etc	Brushing spraying dipping	a) Boiling creosote	—	
				b) Copper naphthenate 1 percent solution	—	Calculated as copper
				c) Zinc naphthenate 1.5 percent solution		Calculated as zinc
				d) Copper abietate 1 percent solution		Calculated as copper
9	Prophylactic treatment for storage of timber etc	a) Timber logs and converted timber	Brushing spraying dipping	a) Sodium pentachlorophenate (Na PCP) 1 percent		
				b) Boric acid borax (1 : 1) 2 to 2.5 percent solution	—	
				c) Gamma BHC 1 percent solution in water dispersible or 2 percent in oil if soluble		
				d) DDT 2 percent in oil		To be preferred for open storage
				e) PCG 2 percent in oil		
		b) Wood carvings blocks for rifle butts textile accessories sports goods etc	do	PEG (1 000) + 1 percent Na PCP + 1 percent borax		
		c) Plywood logs match logs etc	Brush application	Artificial bark		

Penetration of the preservative for

Group 1 — In the case of timbers to be embedded in the ground like transmission poles piles etc it is desirable to have at least 31 mm ring of sapwood and care should be taken that the penetration of the preservative is completed in the entire sapwood portion penetration in the non durable heartwood in addition would ensure a satisfactory service life In the case of sleepers while it is best that the penetration is through and through in the sap and non-durable heartwood portions a minimum penetration of 25 to 40 mm is essential Where the **heartwood of ~~the non-durable~~ timbers** is refractory to treatment incision of all the surfaces except the ends to a depth of 12 to 19 mm is recommended particularly in the case of conifers

Groups 2 to 7 In the case of timbers under Groups 2 to 7 while the sapwood portions should be completely treated for all timbers a minimum penetration of 19 mm in the case of Groups 2 and 4 12 mm for Group 5 and 6 mm for Groups 6 and 7 is essential

NOTE 1 — Percentages in col 5 refer to strength of solution to be used for dipping soaking brush or spray treatment For pressure and open tank treatments the absorptions are indicated in col 6 and refer to the non durable portions of the timbe Unless stated otherwise the above treatments ensure protection against fungal decay termite and borer attack The absorptions given under col 6 against Group 6 shall enable repeated use of the treated material, provided suitably strong timber is used originally

NOTE 2 — Wherever an individual value of recommended absorption is made it shall be taken as minimum

NOTE 3 — For water-soluble and organic solvent type of preservatives the absorptions mentioned against them refer only to dry chemicals present in them

NOTE 4 — For treatment of packing cases for foodstuffs pencil slats only boric acid borax treatment should be given

*Use of CCA in packing cases should be restricted as most of the packing cases find their way in household fuel where arsenic can be hazardous

c) Hot and cold process is most convenient for structural timbers when pressure cylinders are not available. The timber to be treated is heated in tanks containing hot preservative solutions (for oil type) or in hot water (for water soluble preservatives) for about two to three hours (by which the air in timber is expelled) and then the timber is allowed to cool in the same tank, along with the cooling of preservative (for oil type preservatives) or it is transfered to another tank containing cold preservative (for water soluble preservatives). In this process the preservative enters the wood to replace the expelled air. The cooling time is adjusted according to the absorption required.

4.5 Fire-retardant Treatments

4.5.1 Of all types of so called combustible materials used in buildings, wood can perhaps be rated as safest. The two principal criteria to divide the fire performance of the building materials are: (a) fire resistance, that is, how long it takes before the material can resist heat or flame before losing its basic strength, and (b) fire hazard which is rated on the basis of its surface inflamability or combustibility. Since wood is also a combustible material, it will be necessary to treat it with fire retarding chemicals particularly where incidence of fire is likely to take place. There is no treatment which would make the material completely fire-proof, but a number of chemicals can retard the combustion and reduce the glow in timber.

4.5.2 *Fire-retarding Chemicals* — Some of the chemicals like ammonium sulphate and ammonium phosphate are only fire retardants. A mixture of the two in the ratio of 4 : 1 is found to be fairly effective. There are other types which are fire-retardant-*cum*-antiseptic compositions. These provide some resistance to decaying organisms also. Inorganic salts, such as boric acid, borax, zinc chloride with or without preservatives such as copper sulphate have proved useful; but these are corrosive to metals used as fastners in timber joints. Hence limited amounts of potassium or sodium dichromates are added to reduce corrosiveness. The following are some of the well tried compositions:

a) Sodium tetraborate and boric acid in the ratio of 3 : 2;

b) Ammonium borax-boric (ABB) composition comprising ammonium phosphate, ammonium sulphate, borax and boric acid in the ratio of 1 : 6 : 1 : 2;

c) Chromated zinc-ammonium-boric composition (CZAB) comprising sodium dichromate, zinc chloride, ammonium sulphate and boric acid either in the proportion of 4 : 4 : 1 : 1 or in the proportion of 1 : 7 : 7 : 5, both of which are effective; and

d) Chromated zinc-ammonium-copper-boric composition (CZACB) comprising sodium dichromate, zinc chloride, ammonium phosphate, copper sulphate and boric acid in the proportion of 3 : 5 : 3 : 1 : 3.

A number of compositions of varying proportions of some of the above are available in markets under trade names, such as pyrolith, celcure-F, ASCU-C, etc. It way be noted that most of these chemicals are leachable and also hygroscopic which may render them less suitable for decorative members in exterior conditions. Fire retardents based on water soluble monomers subsequently polymerizing in wood are of resin type and can stand to weather conditions fairly well. Hence they can be used for roof shingles, fence posts, etc. They do not also stand in the way of any subsequent paints and varnishes required.

4.5.3 *Treatment Methods* — Simple brush, dip or immersion treatments are not generally sufficient as heavy dry salt loadings are required for effective control of flame spread. The full-cell pressure treatment recommended in **4.4.4.1** is the most suitable for this purpose. However, a penetration of about 1.5 cm deep from the surface may be sufficient, but heavy absorption as indicated below in Table 16 is recommended.

TABLE 16

(*Clause* 4.5.3)

MINIMUM DIMENSION OF CROSS-SECTION OF THE MEMBER cm	ABSORPTION kg/m³
up to 5	40-48
5 to 10	32-40
10 to 20	24-32
more than 20	12-24

4.6 Other Processes and Wood Products

4.6.1 Besides the above, there are quite a number of processing techniques for improving the quality of wood but which are not of much relevance in the limited scope of the Handbook. However, a passing mention of the same would keep the engineer informed of the potentialities of wood utilization. Also some of the products developed under these processes are already in use for some of the non-structural uses of wood in buildings, such as doors and windows. Some of these are described below very briefly.

4.6.2 *Panel Products* — This is a general term used for plywood, hardboards, particle boards, insulation boards and block boards which are already extensively used in building industry. There are a variety of these products available in the market. Some are made for decorative purposes and some are intended for general purposes. Some of these are gradually coming into use even for structural purposes, but in all such cases the strength data is generally obtained on specific product. Corresponding Indian standards have been evolved for these products and evaluation of their properties; and these are also referred below for ready reference:

a) *Plywood* — IS : 303-1975 covers the manufacture and classification of plywood for general purposes; IS : 1328-1970 deals with veneered decorative plywood; IS : 7316-1974 deals with decorative plywood using plurality of veneers for decorative faces; and IS : 4990-1981 deals with plywood for concrete shuttering work. In the manufacture of these products, thin veneers are first taken out from logs on big peeling lathes or slicers.They are properly dried and glued to each other with grain direction generally running at right angles to each other in alternate layers. The quality of plywood is tested as per IS : 1734 (Parts 1 to 20)-1972 depending on the end requirement. The most important quality of plywood, in general, is its glue shear strength and its capacity to hold the laminations together under various circumstances of use. The general purpose plywood is thus broadly graded as: (1) CWR (cold water resistant), (2) WWR (warm water resistant), (3) BWR (boiling water resistant), and (4) BWP (boiling water-proof) for which appropriate adhesives and species are chosen to make the plywood of required choice.

b) *Fibre boards* — These are also referred as hardboards, fibre hardboards and insulation boards. IS : 1658-1977 deals with the manufacture, classification, and standard sizes of fibre hardboards, and IS : 3348-1965 deals with fibre insulation boards as they are available in Indian markets. These are principally products made of wood pulp, defibrated and pressed under hot presses. Recently decorative hardboards have come into vogue. Several types of plastic surfaced, enamelled, moulded, perforated, embossed, printed, and paper-overlaid hardboards are gradually coming into markets. These building boards have fairly good strength, insulation and accoustic properties. The density of the board and annealing treatments are important characteristics of the hardboards on the basis of which they are classified.

c) *Particle boards*—Dry wood, appropriately chipped into small 'particles' and made into panel forms by suitable adhesives are known as 'particle boards'. A variety of them, both for general as well as for decorative purposes, are already available in Indian markets, though the actual use of this product in India is not as extensive as in other countries. These have also been used for structural purposes in other countries. IS : 3478-1966 deals with high density particle boards, and IS : 3129-1965 deals with low density particle boards. In addition to wood particles, other cellulosic materials like bagasse, have also been successfully used for production of these type of panels. Decorative aspects are alo obtained by overlaying with decorative laminate. IS : 3097-1980 deals with veneered particle boards. Considerable amount of R & D work is still going on in the country for producing improved varieties of particle boards and their use in diverse fields. Quality of these boards are tested according to IS : 2380 (Parts 1 to 12)-1977.

d) *Block boards* — These are sometimes referred also by the general term 'core board', which also includes 'batten boards' and 'laminboards' or 'lamin wood'. However, in block boards the core is made of strips of wood 2.5 cm wide, laid adjacent to each other, to form a sort of core slab and then covered by glued veneers with the direction of the grain of core strips running at right angles to that of adjacant veneers. IS : 1659-1965 deals with block boards. These are widely used in furniture panelling, shutters, etc. Some of the block boards are made decorative by laying ornamental veneers on one of the faces.

e) *Flush doors* — A sizable industry has come up in India producing flush doors for use in modern buildings, replacing the old type of slid panel doors. However owing to malpractices, and production of inferior types of doors, serious doubts have been entertained in some quarters and trends have been reverted to panel doors in those quarters. This may not remain a permanent feature. Realizing the several advantages of flush doors, more and more flush doors will be utilized if their quality is assured. IS : 2191 (Parts 1 and 2)-1980 deals with wooden flush doors with cellular and hollow core and with plywood or particle board, or hard board face panels and IS : 2202 (Parts 1 and 2-)1980 deals with wooden flush doors with solid core faced with plywood, or particle boards and hardboards. Quality tests for these doors are now made severe to avoid any malpractices. For determining the quality of these doors, a series of type tests are also given separately in IS : 4020-1967. These doors are sometimes made decorative with overlaying of ornamental veneers, etc (*see also* **6.2.16**).

f) *Glued laminated structural members* — Based on experiences in other countries, new trends are developing in the country also for producing laminated structural units from even inferior grade timber. With the help of synthetic adhesives, planks of wood from 2 to 5 cm can be suitably laminated to get any thickness and any length. Even curved members can be produced where desired. In such places where the stresses are comparatively low (that is neutral surfaces of beams.etc), low grade timber can also be used, and strong timbers can be used at the outer layers where higher stresses come into play. Apart from the cost, several factors are involved in producing these structural units, such as glueability of the species; preparation of the laminates, suitable adhesives for cold pressing for exterior use, and the fabrication and pressing equipment. Although designed structural units are not readily available in Indian markets, there is a great potentiality for development in this field as timber engineering progresses in the country.

5. TIMBER DESIGN—PART I

5.1 General Considerations

5.1.1 When designing a structural component or full structure in timber, careful selection is to be made of species economically available in the local markets. All the properties of the species, such as strength, durability, treatablity and refractoriness should be carefully assessed. Where necessary, the processing and treatment facilities should be explored. After deciding on appropriate grade of the material for the required purpose, proper facilities for storage of the material, and *in-situ* fabrication and erection should be ensured. Availability of other material used in timber constructions, such as nails, screws, bolts and nuts, connecters to be used, and adhesives where required, should be ensured according to relevant standards.

5.1.2 In design considerations, NBC has recognized some basic factors which require to be ensured under all conditions. All structural members, assemblies, or frame work in a building in combination with other units of the building, should be capable of sustaining, for the required duration, the worst combination of all loadings without exceeding the limits of specified stresses for the species and at the worst are weakest location of structure. The NBC has also prescribed, the various types of loads that should be considered for different structures. These are applicable to timber structures also. Based on IS : 875-1964, suitable dead loads and live loads or imposed loads should be assumed. There is no specific guidance as yet in this country for the varieties of combination of dead loads and imposed loads with specific reference to varieties of species of wood. Wind and seismic forces are, however, not considered to act simultaneously. As in timber members, boring, grooving, etc, may be required at different places, the least net section of the member is to be obtained by deducting from the gross section, the projected area of the material removed by wood working operations. Such net sections are obtained by passing a plane, or a series of connected planes transversely through the members. However, in case of nailing, the area pre-bored is not taken into account, and no notch or groove in any case should remove more than one quarter of the section. Also in the design of intermediate and long columns, gross section is used in calculating load carrying capacity of the column.

5.1.3 Timber has a property of withstanding higher stresses for short periods than for longer periods or permanently. Hence, while considering the various types of loading on timber components, the duration of such loading is required to be assessed. The permissible stresses of different groups of species, and different grades used in different locations are to be modified further by multiplying with a factor K_2, given in the Table 17.

TABLE 17 MODIFICATION FACTOR K_2 FOR DIFFERENT DURATIONS OF LOADING

(*Clause* 5.1.3.)

DURATION OF LOADING	MODIFICATION FACTOR K_2
Continuous	1.0
Two months	1.15
Seven days	1.25
Wind and earthquake	1.33
Instantaneous or impact	2.00

5.1.4 The NBC recognized a further modification factor K_1 with which the permissible stresses require to be multiplied for changes in slope of grain, when the timber has not been properly graded, and contains major defects within the permissible limits. These factors are given in the Table 18.

TABLE 18 MODIFICATION FACTOR K_1 TO ALLOW FOR CHANGE IN SLOPE OF GRAIN

(*Clause* 5.1.4.)

SLOPE	MODIFICATION FACTOR K_1	
	Beams, joists and ties	Columns and posts
1 in 10	0.80	0.74
1 in 12	0.90	0.82
1 in 14	0.98	0.87
1 in 15 or more	1.00	1.00

5.2 Beams (Flexural Members)

5.2.1 In the design of beams the principal considerations are :

a) Form, size and shape of the flexural member,

b) Bending stresses or extreme fibre stress,

c) Prevention of lateral buckling,

d) Shear stresses,

e) Deflections, and

f) Bearing at supports or under load points.

5.2.2 The NBC recognized some general considerations on the size and shapes of beams. The minimum width of the beam or any flexure member should not be less than five centimetres, or one fiftieth of the span whichever is greater. The depth of the beam or any flexure member should not be taken more than three times its width without lateral stiffening. All such members having a depth more than three times its width or a span exceeding fifty times its width or both, should be laterally restrained from twisting or buckling and the distance between such restraints should not exceed fifty times its width. In U K the maximum depth to width ratio varies from 2 to 7 depending upon end fixing and stiffeners employed. The deflection in the case of all members under bending loads should not exceed 1/360 of the span, if such loads are caused due to brittle materials like gypsum ceilings, slates, tiles, etc. In other cases, it should not exceed 1/240 of the span and in case of cantilever, it is 1/180 of the freely hanging length. In deciding these limitations, experiences gathered in the country and also in other countries have been considered keeping in view that wood is an orthotropic material with three principal axes of symmetry and shows strains due to component stresses in all the three planes governed by the three axes. In making any wood working operation, it should be ensured that notches are not unduly made except in top or bottom faces, neither deeper than 1/5 of the depth of the beam, nor further than 1/6 of the span from the edge of the support. Also holes larger in diameter than 1/4 of the depth should not be bored in the middle-third of the depth and length. If holes or notches occur at a distance greater than 3 times the depth of members from the edge of nearest support, only the net remaining depth is used in determining the bending stresses. In all cases it is desirable to calculate local stresses and ensured to be within permissible limits.

5.2.3 In calculating the extreme fibre stress the well known equation developed on theory of bending is :

$$f = \frac{My}{I} = \frac{M}{Z}$$

where

f = extreme fibre stress,

M = bending moment,

y = distance of extreme fibre from neutral plane which for all practical purposes is assumed located at central place of the beam,

I = moment of inertia of cross-section (in cm^4), and

Z = modulus of section in cm^3.

The values of I and Z for different cross-sections can be found in any standard book on strength of materials.

For rectangular beams $I = \frac{bd^3}{12}$ and $Z = \frac{bd^2}{6}$

Since the strength of wood in tension is much greater than in compression it is unreasonable to expect wood to behave like other homogeneous and isotropic materials. Experiments have shown that fibre-stress at elastic limit in bending is far greater than that obtained under pure compression parallel-to-grain and lower than that obtained under pure tension parallel-to-grain and lower than that obtained under pure tension parallel-to-grain. The explanation for this is obvious from the structure of fibres in wood material which lend gradually increasing support to adjacent fibres starting from neutral plane to the extreme fibres. Thus, there is variable influence of neighbouring fibres to the extreme fibres, depending upon the homogeneity and also the cross-section of the beam whether it is rectangular, square, circular beam, or box-beam or an I-beam. Hence various form factors (K) are indicated in **5.2.4** for different types of cross-sections. These should be used as multipliers in the beam formula so that the resisting moment,

$$M = K.f.Z. \text{ or } K.f.I/y$$

5.2.4 *Form Factors for Different Cross-sections of Beams*

a) *Rectangular section* — For different depths of beams more than 30 cm, the form factor recommended in NBC is

$$K_1 = 0.81 \left\{ \frac{D^2 + 894}{D^2 + 550} \right\}$$

This is obtained from a series of tests on different beams, and for ready reference given in Table 19.

TABLE 19 VALUES OF D AND K_1

(*Clause* 5.2.4)

D cm	30	35	40	45	50	55	60
K_1	1.00	0.97	0.94	0.92	0.90	0.89	0.88

NOTE 1 – However in UK, both for solid and laminated beams which are mostly of soft woods, this factor is applied only for beams greater than 30 cm and is given in BSCP 112 : Part 2 : 1971

$$K_1 = 0.81 \left\{ \frac{D^2 + 92\,300}{D^2 + 550} \right\}$$

NOTE 2 In USA, based on a series of tests of beam up to 30 cm, the formula for modification factor is given below and the same is adopted in Australia also

$$K_1 = 1 - 0.07 \left[\sqrt{\frac{D}{2}} - 1 \right]$$

b) For a square section, where the load is applied in the direction of a diagonal, the form factor K_3 is taken in all countries as 1.414. This is justified because the moment of inertia of a square, about a neutral axis perpendicular to its sides is the same as the moment of inertia about a diagonal, and since the bending moment is directly proportional to I and inversely proportional to y it seems necessary to use a form factor. The distance of neutral axis to extreme fibre of a square beam y with a vertical diagonal is $\sqrt{2}$ times as great as that for a beam with vertical sides. Hence for for the same load the resisting moment is $\sqrt{2}$ or 1.414 times the usual one.

c) For beams of circular section a similar condition exists. Tests have shown that a beam of circular section will sustain practically the same load as a square beam of equal area. The section modulus Z for a square is approximately 1.18 times that of a circle of equal area. Hence, in all countries the modification form factor K_5 is 1.18.

d) For box-beams and I-beams the form factor K_4 arises out of different situation. Only the fibres lying within the projection of the width of the web get complete supporting action similar to that in a solid beam. The fibres outside the projection of the width of web that are influenced by loads are in the compression flange and so its depth is important. Thus, of the same height and section modulus, the I.-beam or box-beam is weaker than a solid beam of the same height and section modulus. It is difficult to evaluate the exact interacting support of the fibres, but based on experimental evidence and associated theoretical considerations, various formulae have been worked out in the different countries. If the width of the flange of I-beam or box-beam is t_2 and the width of the web in the I-beam, or combined thicknesses of web in box-beam is t_1, the supporting ability of the compression flange is considered to be $\frac{Q(t_2 - t_1)}{t_2}$ times the supporting ability of the rectangle of t_2 width, and similarly the supporting ability of the web is considered to be t_1/t_2 times the ability of rectangle of t_2 width; where Q depends on P_1 which is the ratio of the thickness (that is, depth) of compression flange to the total depth d, of the beam. Since the increase in fibre stress at elastic limit in flexure over the direct compression is about 72 percent, the increased amount in the I or box-beam can be written as:

$$0{\cdot}72\left[Q\left(\frac{t_2 - t_1}{t_2}\right) + \frac{t_1}{t_2}\right]$$

Thus the modification factor becomes:

$$K_4 = \frac{1 + 0{\cdot}72\left[Q\left(\frac{t_2 - t_1}{t_2}\right) + \left(\frac{t_1}{t_2}\right)\right]}{1{\cdot}72}$$

$$= 0{\cdot}58 + 0{\cdot}42\left[Q\left(\frac{t_2 - t_1}{t_2}\right) + \left(\frac{t_1}{t_2}\right)\right]$$

and now considering for the stresses like modulus of rupture, which are beyond elestic limit,

$$K_4 = 0.50 + 0.50\left(Q\frac{t_2 - t_1}{t_2} + \frac{t_1}{t_2}\right)$$

The same factor is used in Australia also and the relationship of Q to P_1 is given below. A smooth curve between Q and P_1 gives the values of Q for intermediate values of P_1.

P_1	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.0
Q	0.085	0.230	0.400	0.575	0.740	0.875	0.985	1.00

Based on similar arguments, some earlier publications in Europe, and also earlier experience in India, NBC recommends a modification factor:

$$K_4 = 0.8 + 0.8Y\left(\frac{D^2 + 894}{D^2 + 550} - 1\right)$$

where $Y = p_1^2\ (6 - 8p_1 + 3p_1^2)\ (1 - q_1) + q_1$

where D and p_1 are the same as above and q_1 is the ratio of total thickness of web (or webs in the case of box-beam) to the overall width of the beam (t_1/t_2). BSCP 112-1952 gives the modification factor for I-beam and box-beam in terms of ratio of t_1/t_2 and d_1/d_2 reproduced in Table 20 (*see* Fig. 5). In these days, solid wood I-beams and box-beams are not much in vogue in current design trends, and usually plywood web beams are employed. In calculation of bending stresses in the case of such beams, there are four methods in common practice and the designer is left to decide on the best for his own purpose. These are briefly described below.

The homogeneous beam method--In this method, the web is treated as a homogeneous section with the rest, as in rolled steel beams and the modulus of section Z is given by :

$$Z = (I_f + I_w)/(d/2)$$

where I_f is the moment of inertia of cross-section of the flange

$$= \left(\frac{t_2 - t_1}{12}\right)(d^3 - d_1^3)$$

I_w is the moment of intertia of cross-section of web

$$= \frac{t_1}{12}d^3$$

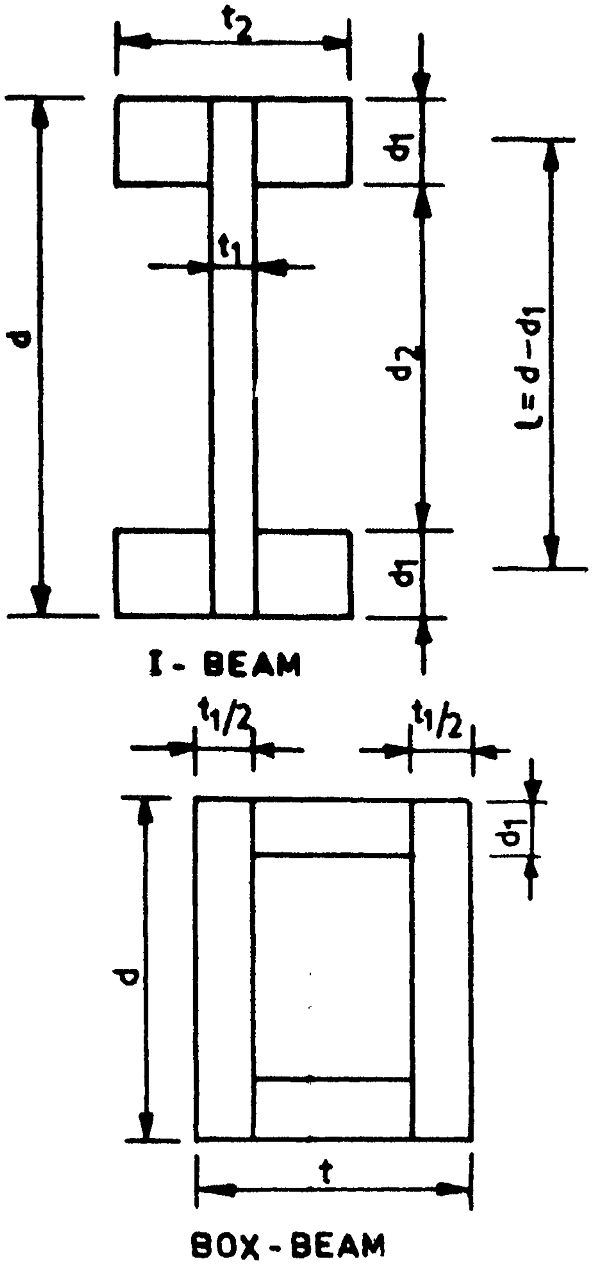


FIG. 5

$$\text{or } Z = \frac{(t_2-t_1)\ (d^3-d_1^3) + t_1 d^3}{6d}$$

The maximum moment capacity is given by $M = fZ$.

The lever arm method This is an approximate method and neglects the contribution made by web in resisting bending. The sections considered are the compression flange (A_c) and tension flange (A_t) having their centres at a distance $f = (d-d_1)$ In this case. $Z = A_c\ (d-d_1)$ or $A_t\ (d-d_1)$ and the bending moment is given by $M = f(d-d_1)\ A$ or $f\ (d-d_1)\ A_t$

If A_c and A_t are not exactly equal, the lower value is taken.

The flange modulus method This is more or less same as above. where the contribution of web is neglected, but extreme fibre stress is more accurately assessed by taking full depth into consideration and I of the beam as :

$$Z = \frac{I_f}{d/2} = \frac{1}{6d}(t_2-t_1)(d^3-d_1^3)$$

The exact method Here the beam is considered as a composite of two materials, and the calculation of the bending moment is done on the theory of composite elements, that is,

$$M = M_f + M_w$$

$$\text{or} \qquad E = F_f I_f + E_w I_w$$

where the suffixes f and w indicate for flanges and webs; the bending moment M. the modulus of elasticity E, and the moment of inertia of cross-section I. Similarly if f_f and f_w represent the fibre stress of flange and web materials, then

$$M = \frac{2(E_f I_f + F_w I_w) f_f}{E_f d};\ Z = \frac{2(E_f I_f + E_w I_w)}{E_f d}$$

where f_f is in consideration;

$$\text{or } M = \frac{2(E_f I_f + E_w I_w) f_w}{E_w d};\ Z = \frac{2(E_f I_f + E_w I_w)}{E_w d}$$

where f_w is in consideration.

TABLE 20 MODIFICATION FACTOR FOR FLEXURAL STRESSES IN MEMBERS OF I OR BOX SECTIONS

RATIO t_1/t_2	RATIO d_1/d								
	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
	Modification factor								
0.1	0.65	0.68	0.71	0.74	0.77	0.81	0.84	0.87	0.90
0.2	0.69	0.72	0.74	0.77	0.80	0.83	0.86	0.88	0.91
0.3	0.73	0.75	0.77	0.80	0.82	0.85	0.87	0.89	0.92
0.4	0.77	0.79	0.81	0.83	0.85	0.87	0.89	0.91	0.93
0.5	0.81	0.82	0.84	0.85	0.87	0.89	0.91	0.93	0.95
0.6	0.85	0.86	0.87	0.88	0.90	0.91	0.93	0.94	0.96
0.7	0.88	0.89	0.90	0.91	0.92	0.94	0.95	0.96	0.97
0.8	0.92	0.93	0.93	0.94	0.95	0.96	0.96	0.97	0.98
0.9	0.96	0.96	0.97	0.97	0.97	0.98	0.98	0.98	0.99
1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The lower value of M is to be considered depending on the respective values of E_f, f_f, E_w, f_w of the material of flanges and webs. Substituting for I_f and I_w in terms of dimensions the above equations become

$$M = \frac{E_f(t_2 - t_1)\ (d^3 - d_2^3) + E_w t_1 d^3}{6d} \cdot \frac{f_f}{E_f}$$

$$\text{or } M = \frac{E_f(t_2 - t_1)\ (d^3 - d_2^3) + E_w t_1 d^3}{6d} \cdot \frac{f_w}{E_w}$$

In these equations if $E_f = W_w$ and $f_f = f_w$ the values of Z and M become the same as in homogeneous beam method.

5.2.5 *Shear Stresses*

5.2.5.1 In calculating shear and vertical reactions the following formulae are employed :

a) General formula : $H = VQ/Ib$

b) Rectangular beam : $H = 3V/2bD$ (*see* note against Q)

c) Notched beams with tension notches and supports that is on the lower face : $H = 3VD/2bD_1^2$

d) Notch at upper (compression) face where $e > D$: $H = 3V/2bD_1$

e) Notch at upper (compression) face where $e < D$: $H = \dfrac{3V}{\left[2b\left(D - \dfrac{D_2}{D}e\right)\right]}$

NOTE — Only the first three are given in NBC.

where

H = horizontal shear (or longitudinal shear) in kg/cm^2 at the level under consideration (usually this is calculated at the neutral axis);

V = vertical end reactions, or shear at a section in kg;

Q = moment of area above the level at which H is considered, about neutral axis. If A is the area of the beam above the level at which H is considered and y is the distance from neutral axis of the beam to the centre of area, then $Q = Ay$.

I = moment of inertia of a section in cm^4 also known in literature as second moment of area of the cross-section under consideration;

b = width of the beam in cm at the level at which H is calculated;

D = depth of the beam in cm;

D_1 = depth of the beam at the notch in cm;

D_2 = depth of the notch in cm; and

e = length of the notch measured along the beam span from the inner edge of the support to the farthest edge of the notch.

e = length of the notch measured along the beam span from the inner edge of the support to the farthest edge of the notch.

5.2.5.2 In determining the vertical reaction V, all uniform loads within a distance equal to the depth of the beam from the edge of the nearest support are neglected. It is well known that concentrated load placed close to the support causes at the neutral plane a much less shear stress than given by simple shear theory. This is because some of the load is transmitted directly to the support without inducing shear stresses in the member. Also the upper and lower halves of the beam act as somewhat independent beams because of inevitable presence of checks, etc. These have been demonstrated experimently and mathematically. Hence all concentrated loads near the supports are, according to NBC, reduced by a factor given in the Table 21. For intermediate distances percentage reduction is obtained by linear interpolation. If any relief is obtained to the beam under consideration by distribution of load to adjacent beams or flooring, this should be given due consideration.

TABLE 21 REDUCTION FACTORS FOR DIFFERENT DISTANCES OF LOAD FROM NEAREST SUPPORT

(*Clause* 5.2.5.2)

DISTANCE OF LOAD FROM THE NEAREST SUPPORT	REDUCTION FACTOR
1.5 *d* or less	0.6
2 *d*	0.4
2.5 *d*	0.2
3 *d* or more	No reduction

If there are moving loads, the largest one should be placed at a distance of 3 times the depth of the beam but not more than ¼ the span. If the member does not qualify for shear resistance by the above procedure, a more accurate evaluation of V is given by:

$$V = \frac{10\,P}{9} \times \frac{1}{l}\,\frac{(1-x)(\frac{x}{d})^2}{2 + (\frac{x}{d})^2}$$

and for uniformly distributed loads,

$$V' = \frac{W}{2}(1 - \frac{2d}{l})$$

where V' = total modified end reaction,
d = depth of the beam,
l = span of the beam,

P = concentrated load,
W = total uniform load, and
x = distance from the reaction to load

5.2.5.3 Thus after obtaining the value of V and substituting in the formula for horizontal shear given in **5.2.5.1**, it should be ensured that it does not exceed the permissible horizontal shear for various species, grades and locations discussed in **3.3** and Appendix H.

5.2.6 *Bearings and Bearing Stresses*

5.2.6.1 Wherever flexural members are supported in recesses, there should be adequate provision for proper ventilation and other protection from wood destroying agents like fungii and insects. It should also be ensured that the bearing surface of wood is well finished to a plane surface, and rests fully and adequately on the supports.

5.2.6.2 For bearings of any length at the ends of a member, and for bearings of 150 mm or more in length at any other position, the permissible stresses are the same given in standard tables for compression perpendiculer to grain (*see* Appendix H). However, for bearings less than 150 mm length, but located 75 mm or more from the end of a member, the permissible stress is equal to the standard working stress in compression perpendicular to grain, multiplied by a modification factor K_7 given in Table 22 is taken from NBC. No allowance is, however, made of differences in intensities of bearing stresses due to bending.

TABLE 22 MODIFICATION FACTOR K_7 FOR BEARING STRESSES

(*Clause* 5.2.6.2)

Length of bearing, in mm	15	25	40	50	75	100	150 or more
Modification factor, K_7	1.67	1.40	1.25	1.20	1.13	1.10	1.00

5.2.6.3 Where wanes are permitted, only the net area should be taken for calculation. Similarly for bearing stresses under a washer, or a small steel plate the same coefficient of Table 22 should be taken for a length equal to the diameter of the washer, or the width of the small plate.

5.2.6.4 When the direction of stress is at an angle θ to the direction of the grain, then the permissible bearing stress f_θ in that member is calculated by the usual Rankinson formula:

$$f_{c\theta} = \frac{f_{cp} \times f_{cn}}{f_{cp} \sin^2\theta + f_{cn} \cos^2\theta}$$

where

$f_{c\theta}$ = permissible compressive stress in the direction of the line of action of the load in kg/cm^2,

f_{cp} = permissible stress in compression parallel to grain in kg/cm^2,

f_{cn} = permissible stress in compression normal (perpendicular) to grain in kg/cm^2, and

θ = angle of load-to-grain direction.

5.2.7 *Lateral Stability (Lateral Buckling)*

5.2.7.1 Lateral stability of a beam is sometimes referred also as lateral buckling is caused by torsional forces occuring in the beam, and this becomes predominent in narrow and deep beams. That is a beam in which ratio D/b or L/b is high where b is the width of the beam. This is also caused due to elastic anisotropy in wood. There are several methods of linking the degree of lateral stability of a timber beam with working stresses in bending. However, the various codes prescribe maximum D/b or L/b ratio only. The NBC does not give any guidance for this, except in general terms of limiting spans, depths and breadth. The critical lateral buckling load in many respects is similar to the critical loads of columns and on the basis of mathematical analysis, formulae have been developed for calculating the critical loads. In order to ensure that failure should not occur by lateral buckling, the total safe load W should be:

$$W \leqslant \frac{C\sqrt{EI'GK}}{L^2}$$

and the same for a rectangular beam is given by

$$W \leqslant \frac{C\lambda . db^3\ E(W_L + W_D)}{41.5 . L^2 . (W_L + 3W_D)}$$

where W = critical buckling loads;

C = a constant depending on condition of loading and fixing (example, for a centilever $C = 4$ with a concentrated load at the end, and $C = 12.9$ with uniformly distributed load. For simply supported beam $C = 16.9$ with concentrated load at the centre and $C = 28.3$ for uniformly distributed load. If the ends are clamped the value of $C = 43.3$);

E = modulus of elasticity in bending;

I' = moment of inertia of the beam about its vertical axis;

L = span;

d = depth of the beam;

b = width of the beam;

W_L = live load;

W_D = dead load;

K = tortion constant of the section and is equal to αdb^3 where α depends on d/b (*see* Table 23);

G = modulus of rigidity in torsion usually taken as $E/16$; and

λ = a constant depending on d/b (*see* Table 23).

TABLE 23 VALUES OF α AND λ FOR DIFFERENT VALUES OF d/b

d/h	1	1.5	2	2.5	3	3.5	4	5	6	7	8	9	10	20
α for K	0.14	0.19	0.23	0.25	0.265	0.27	0.28	0.29	0.297	0.303	0.309	0.31	0.311	0.315
λ	0.375	0.442	0.478	0.499	0.512	0.522	0.530	0.539	0.546	0.550	0.553	0.556	0.558	0.568

From Table 23, it can be shown that if the applied load is limited to the permissible deflection of 1/360 of span, there can be no possibility of lateral buckling if d/b is less than 4.4 and if permissible deflection is 1/200 it is safe if d/b is less than 3.3.

5.2.8 *Deflections*

5.2.8.1 Deflections which reflect stiffness in beams are caused not merely due to bending stresses which cause elongation and compression on extreme fibres but also due to shear stresses, and consequent strains. Even though the latter in most cases are negligible inspite of low modulus of rigidity it is useful to know their contribution and the engineer can-check wherever necessary. This is all the more important in view of the fact that timber is elastically an orthotropic material. Even in ordinary strength tests, the contribution of deflection due to shear is neglected, and so the recorded modulus of elasticity is naturally 10 to 15 percent lower than true value which is on the safer side.

5.2.8.2 Most of the codes prescribe the limitation of deflections for different purposes (*see also* **5.1**). Given the dimensions of the beam for calculating EI values and knowing the loads W, it would be easy to check weather the span in question is adequate to meet the limits of deflection, coded for different purposes; and then the flexural strength for the optimum span can also be checked up. In ordinary cases the deflection of the beam is limited to 1/360 of the span primarily to prevent cracking of plasters, etc, in buildings and particularly when the beam supports brittle materials like gypsum ceiling, slates, tiles, asbestos sheets, etc. For bridges, etc, ratio of 1/200 to 1/300 is recommended, depending on the nature of bridge. In India, it is the practice not to exceed 1/240 in case of simple beams and joists, and 1/180 of freely hanging length in case of cantilevers. In small building constructions, stiffness is more important than deflection.

5.2.8.3 In calculating deflection, the normal deflection formula is employed for different types of loadings and fixings. For various types of some simple loadings, *see* Fig. 6 for bending moment, deflection and shear. For some types of complicated loading, the central deflection may be different from maximum deflection. However, for simply supported beams, for whatever loading, the maximum deflection will not be more than 2.57 percent of central deflection and its position always occur within 0.077 L of the centre of span. For checking up the permissible deflection in case of timber beams, the load is taken as twice the dead load + ¾ of the live load (IS : 883-1970). In recent practices in USA, while taking twice the dead load, no reduction is made in the live load. It is customary in all countries to use the average E of the species, except under some special circumstances, when load is shared (*see also* **3.4.5.2**). But as E is a variable quantity some pieces may have 75 percent more or 75 percent less than calculated deflection, and this is neglected. In some of the Australian designs, it has been presumed that for a continually applied load, the value of E is usually about 1/3 of the value obtained in normal laboratory tests with short time loading. Hence $E/3$ is taken for the contribution of dead loads.

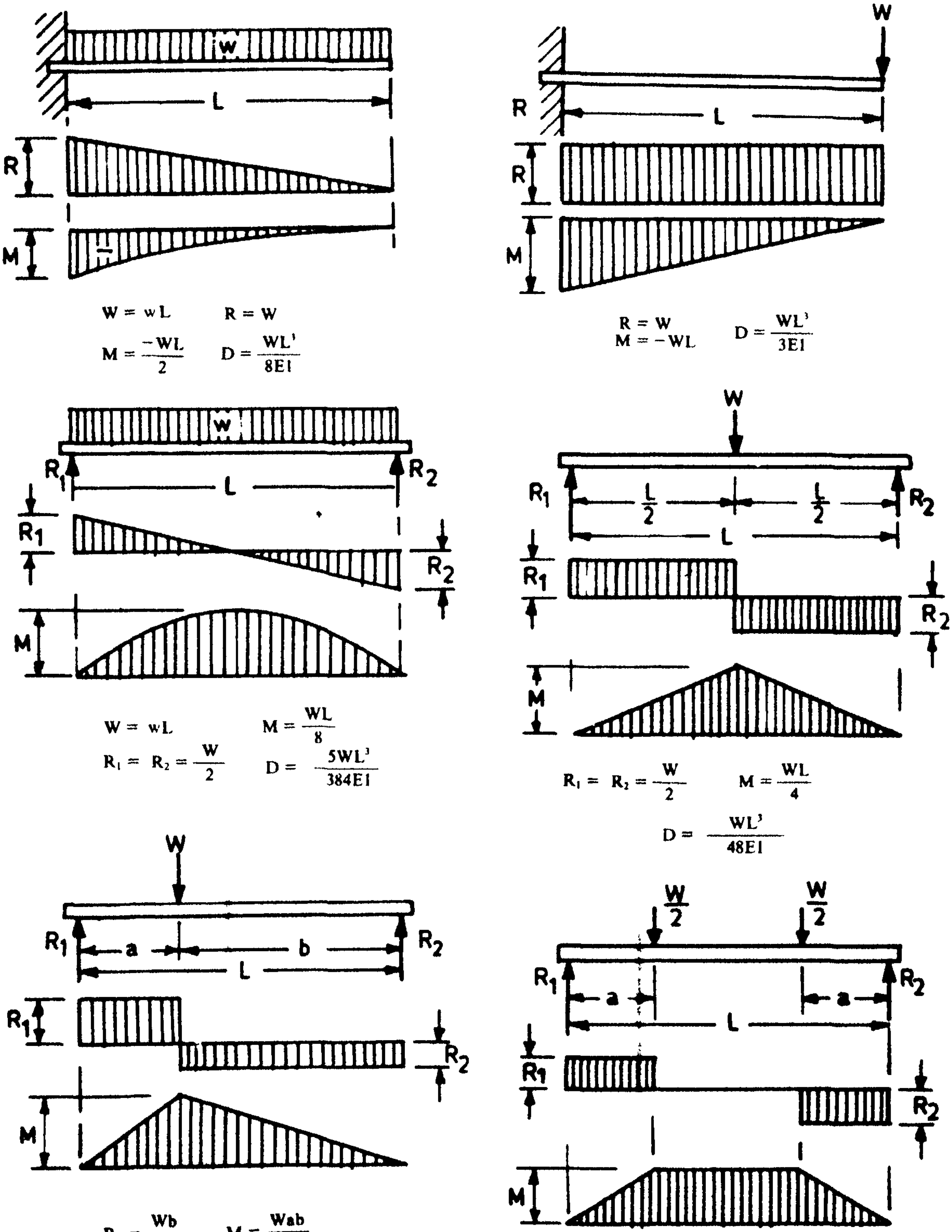
5.2.8.4 As discussed in **5.2.8.1**, the deflection of any beam being a combination due to bending and shear forces, it would be interesting to study in a little more detail the relative importance of both, even if shear deflections are often neglected. For reasons explained in **5.2.8.3**, the deflections are calculated by the usual deflection formula $\frac{WL^3}{KEI}$ which, in the case of central loading is given by $WL^3/48\ EI$ and in the case of uniform loading is given by $\frac{5}{384}\frac{WL^3}{EI}$. Even in the case of any complicated loading it is quite safe to calculate the central deflection from an equivalent uniformly distributed loading for which the deflection at mid-span Δ in such a case is given ordinarily by

$$\Delta = \frac{5\,W_e L^3}{384\,EI}$$

where W_e is the equivalent uniformly distributed ($K_b W$). For the method of evaluating K_b, and so the equivalent load, for various types of loading a reference may be made to Sl No. 54 in Appendix B. Similarly, the deflection due to shear stresses, (except in cases where such stresses do not exist if the beam is subjected to pure bending) is given by:

$$\Delta_s = \frac{F}{AG}\int_0^{+l} V.H.dh$$

which at mid-span $= \frac{FM_0}{AG}$



$W = wL$ $R = W$

$M = \frac{-WL}{2}$ $D = \frac{WL^3}{8EI}$

$R = W$
$M = -WL$ $D = \frac{WL^3}{3EI}$

$W = wL$ $M = \frac{WL}{8}$

$R_1 = R_2 = \frac{W}{2}$ $D = \frac{5WL^3}{384EI}$

$R_1 = R_2 = \frac{W}{2}$ $M = \frac{WL}{4}$

$D = \frac{WL^3}{48EI}$

$R_1 = \frac{Wb}{L}$ $M = \frac{Wab}{L}$

$R_2 = \frac{Wa}{L}$ $D = Wab(L + b)\sqrt{3a(L + b)}$

$R_1 = R_2 = \frac{W}{2}$ $M = \frac{Wa}{2}$

$D = \frac{Wa(3L^2 \times 4a^2)}{48EI}$

FIG. 6 CANTILEVERS

where F = form factor dependant on cross sectional shape of the beam (equal to 1.2 for a solid rectangle),

V = external shear due to actual loading,

H = shear due to unit load at the point where the deflection is being calculated,

A = area of section,

G = modulus of rigidity ($E/16$),

M = bending moment at mid span ($W_0L/8$), and

W_0 = WK_s (W = actual load)

For evaluating K_s for different types of loading a reference may be made to Sl No. 54 in Appendix B. From these discussion the total deflection $\Delta_t = \Delta_b + \Delta_s$ where the suffixes b and s indicate as deflection due to bending and shear forces respectively. When actually worked out, usually Δ_s is between 2.5 and 10 percent which is negligible. If a graph is drawn between L/D and $\frac{\Delta_t}{\Delta_b}$., it will be seen that for values of L/D from 5 to 12, $\frac{\Delta_t}{\Delta_b}$ reduces from about 1.6 to 1.1; for values of L/D more than 12 and up to 25, the ratio of $\frac{\Delta_t}{\Delta_b}$ reduces from 1.1 to about 1.025.

5.2.9 *Camber*—There is no specific guidance on the subject in any of the timber engineering codes. Camber is, however, considered important particularly in built-up beams, so that under the action of dead-loading the beam settles down to approximately a horizontal position. In all these cases, a certain amount of engineering judgement will be necessary, how to work out the camber, and what modulus of elasticity may be taken. It should be remembered that it is often easier to adjust the erection if there is slight residual camber than if there is any sag. In the earlier days, when tension rods were being employed in the trusses, camber could be obtained by adjusting the nuts in the tension rods. A few moments of thought on the subject at the time of design will save considerable embarrassment at erection and subsequent behaviour of the beam in use.

5.3 Columns

5.3.1 In preparing columns or compression members, it is essential that there should be no notches or cuts in the same. However, when services have to be necessarily passed through such members, it can be effected by boring a hole of a diameter not more than one fourth of the width of the face on which it occurs, and the distance from the edge of the hole to the edge of the member should not also exceed one fourth of the width of the face. It should be further ensured that the centre line of action of the force due to load coincides with the axis of the member. Eccentric loadings may result in erroneous calculations and undue deformations.

5.3.2 The principal considerations in the design of columns are axial stress and its duration, positional restraints of ends, directional restraints of ends (fixing), lateral restraints along the length, effective length, slenderness ratio (S/d), deflected form, bearings at top and bottom. The NBC has dealt with only axial stress and slenderness ratio. In NBC, the duration aspect is dealt in a common way for all types of stresses in constructional members.

5.3.3 Columns of soild timber are classified as:

a) short columns where S/d (slenderness ratio) does not exceed 11, and permissible stresses are same as given in standard tables, that is, standard working stress for compression parallel to grain (f_{cp}) (*see* Appendix H);

b) intermediate columns where S/d is between 11 and K_8 (*see* below) and the permissible stresses are obtained by multiplying standard working stresses for compression parallel to grain by $\left[1 - \frac{1}{3}\left(\frac{S}{K_8 d}\right)^4\right]$ based on the fourth power parabolic formula developed in USA. This formula is, however, dependent on the assumption that the compressive stress at proportional limit is 2/3 of maximum crushing stress and that the shape of the curve below $S/d = K_8$ is parabolic and at $S/d = K_8$ this curve is tangent to the Euler curve for long columns; and

c) long columns where L/d is greater than K_8 and the permissible stress is given by $0.329E/(S/d)^2$. This is on the assumption that only 2.5 factor of safety is used which is different from that recommended in 3.3 and Table 13. Without the factor of safety the constant will work out to 0.818 instead of 0.329.

where S = unsupported overall length of the column in cm,

d = dimension of least side of the column in cm,

$K_8 = 0.702\sqrt{E/f_{cp}}$,

f_{φ} = working stress in compression parallel to grain in kg/cm^2, and

E = midulus of elasticity in kg/cm^2.

5.3.3.1 The general equation for long column of uniform cross-section when end fixing are considered is obtained from the well known Euler formula in which

$$\frac{\text{Load on column } (P)}{\text{Area of cross-section } (A)} = \frac{K\pi^2 E}{(S/r)^2}$$

where K = constant depending on end fixity, and is equal to 1 for pin ended column, and 4 for fixing ends, and radius of gyration $(r) = d/12$ [*see* 5.3.7(1)].

It has been prescribed in NBC that in solid columns of timber, S/d ratio should never exceed 50. Rules have also been prescribed for tapered columns. The induced stress at the small end should not exceed the working stress in compression parallel to grain. For determining S/d ratio in such a case, the least dimension d should be taken as sum of: (a) the least dimension at the smaller end, and (b) 1/3 difference between the least dimension at larger end and corresponding least dimension at small end. In any case the so computed least dimension should not exceed 1½ times the least dimension of the smaller end. In USA the equivalent area of a long tapered column is taken at a point 1/13 of its length from the bottom of the column (that is, larger end). In designing a round column, first a square column is designed and then the diameter of equivalent cross-sectional area is computed.

5.3.4 Many instances arise when it is economical to build up columns from smaller sizes. Similar to the above classification, such built up columns and box columns also are classified as:

a) short columns where $S/\sqrt{d_1^2 + d_2^2}$ is less than 8; and the permissible compressive stress f_c if given by $f_{cp}q$;

b) intermediate columns where $S/\sqrt{d_1^2 + d_2^2}$ is between 8 and K_9 and the permissible compressive stress f_c is given by:

$$f_c = qf_{cp}\left[1 - \frac{1}{3}\left\{\frac{S}{K_9\sqrt{d_1^2 + d_2^2}}\right\}^4\right]$$

or $$f_c = qf_{cp}\left[1 - \frac{S^4}{3(K_9)^4(d_1^2 + d_2^2)^2}\right]$$

c) long columns where $S/\sqrt{d_1^2 + d_2^2}$ is greater than K_9 and permissible compressive stress f_c is given by:

$$f_c = \frac{0{\cdot}329\ UE}{\left(\dfrac{S}{\sqrt{d_1^2 + d_2^2}}\right)^2}$$

or $$f_c = \frac{0{\cdot}329\ UE\,(d_1^2 + d_2^2)}{S^2}$$

where S and f_{cp} have the same notation as above,

d_1 = the least overall width of the box column in cm,

d_2 = the least overall dimension of core in box column in cm, and

K_9 = constant equal to

$$\frac{\pi}{2}\sqrt{\frac{UE}{5q\,f_{cp}}}$$

and U and q depend on plank thickness as follows:

Plank thickness, t cm	U	q
2.5	0.80	1.00
5.0	0.60	1.00

Table 24 shows the strength of builtup column as a percentage of solid column of equal height, size and grade. In building up the column, it should be ensured that the width of the plank is not more than 5 times the thickness and the nails penetrate at least three planks. The nails should also be spaced in longitudinal direction at a distance equal to six times the thickness of one plank. When S/d ratio is 10 or greater, the same percentages given in the Table 24 can be considered for butt-jointed pieces also.

TABLE 24 BUILT-UP COLUMNS STRENGTH AS PERCENTAGE OF SOILD COLUMN

L/d ratio	6	10	14	18	22	26
Percentage of solid column strength	82	77	71	65	74	82

5.3.5 Similar to the above classification, spaced columns also are classified as short, intermediate and long spaced columns. The formula for solid columns described in 5.3.2 is applicable to spaced columns also with a restraint factor F = 2.5 or 3 depending upon distances of end connectors in the column. However, for intermediate spaced column the permissible compressive stress f_c is given by:

$$f_c = f_{cp}\left[1 - \frac{1}{3}\left(\frac{S}{K_{10}d}\right)^4\right]$$

and for long spaced columns it is given by:

$$f_c = f_{cp}\frac{0.329\ EF}{(S/d)^2}$$

where all notations are the same as before and

$$K_{10} = 0.702\sqrt{\frac{FE}{f_{cp}}}$$

5.3.6 In Australia the 'eccentric formula' modified to allow the effect of duration of loading is used. This is given by:

$$f_a = \frac{f_c\left(\dfrac{P_L + P_D}{0.8P_L + P_D}\right)}{1 + \dfrac{4e}{b}\sec\theta}$$

where f_a = safe average stress that can be permitted,

f_c = working stress for compression parallel to grain,

P_L = live axial compressive load,
P_D = dead axial compression load,
e = equivalent eccentricity of loading given in terms of L as $L/360$,
b = least dimension of column,
L = effective length of the column,

$$\theta = 99.3 \frac{L}{b} \sqrt{\frac{3f_a (P_L + 3P_D)}{E(P_L + P_D)}}, \text{ and}$$

E = modulus of elasticity.

In B.S. CP 112, combined modification factors available for different slenderness ratio and duration of loading. Derivation of general formulae and expanded values, of modification factors for the above are discussed in Sl No. 54 of Appendix B.

5.3.7 In designing columns, the formulae given in IS: 883-1970 and NBC for columns with pin ends conditions shall be used and they shall be modified depending on the end conditions. But the practice in other countries is to determine the 'effective length' which depends on the condition of end fixing and whether a sway is permitted or not in the columns. In timber design, it appears only two cases are important. They are: (a) when the ends are fixed in position in which case actual length is the effective length, and (b) when one end is fixed in position and direction, and the other end is free in which case the effective length is taken as twice the actual length. In UK a further distinction is also made on the mode of fixing the ends. If both the ends are pin joints, then the effective length is the total length; if one is pin jointed and the other is fixed end, then it is 0.85 of total length; if both the ends are fixed ends, then the effective length is 0.7 of actual length. Similarly for the effective cross-section, open holes and notches must be deducted from the area, but no such deduction will be necessary for nails, tight bolts with only nominal clearance, etc.

5.3.8 For convenience and easy calculations, in the NBC and in many publications in India, the slenderness ratio is defined as the ratio of the length of the column to its least cross-sectional dimension. However, keeping in view the basic mechanics of action, it should be remembered that 'radius of gyration' is regarded as a measure of dispersal of any area about a given axis. The radius of gyration $R = \sqrt{I/A}$ where I is the second moment of the area and A is the area. The slenderness ratio (SR) is strictly defined and adopted in some countries as:

$$S\,R = L/R = \frac{\text{effective length}}{\text{radius of gyration}}$$

If the directions of buckling are denoted by x and y then the larger value of $(S/R)_x$ or $(S/R)_y$ (that is, the smaller values of R_x or R_y when effective length is the same in both the directions) will determine. In the rectangular sections, since R can be linked to the least cross-sectional dimension d, it is more easy to express slenderness ratio merely as L/d.

5.4 Combined Stresses

5.4.1 When any member is subjected to both bending and axial stresses, then it is said to be under the action of combined stresses. All necessary precautions taken for individual types of stresses are required to be taken for this purpose also, and the design shall comply with the formula (*see* NBC and IS : 883-1970).

$$\frac{f_{ac}}{f_c} + \frac{f_{ab}}{f_b} \text{ is not greater than 1.}$$

where f_{ac} = calculated average axial compressive or tensile stress,
f_c = permissible axial compressive or tensile stress respectively,
f_{ab} = calculated bending stress in extreme fibre in kg/cm^2. and
f_b = permissible bending stress in extreme fibre.

5.4.2 When the end loads, side loads and eccentricity exist together in a column, special formulae are required to be used. There is not much experience in India on these aspects. Some of these formulae can be found in Sl No. 49 of Appendix B.

In Australia the following general formula is recommended for the required cross-section:

$$A' = \frac{P}{f_c}\left[1 + 4\frac{e}{b}\sec\theta\right] + \frac{6M}{df_b\left[1 - \frac{PL^2}{10EI}\frac{(W_L + 3W_D)}{(W_L + W_D)}\right]}$$

when the notation in general is the same as given earlier and

W_L = live transverse load,
W_D = dead transverse load, and
f_b = permissible stress in bending.

Since the term in brackets in the denominator of the second term on right hand side of above equation is nearly 1, and since the first term represents the area required as a column (*see* 5.3.6) the above equation can be written as:

$$A' = A + 6M/df_b$$

5.4.3 When in the design of any structure, particularly framed structure, proper consideration is to be given to sway, a limit should be standardized for the same. Many building codes do not provide for this. A guide limit of 0.003 × height for the design consideration of sway has been suggested in Sl. No. 54 of Appendix B.

6. TIMBER DESIGN—PART 2

6.1 Timber Trusses

6.1.1 *Introduction* Because of the very nature of material and the long traditions in the use of timber for trusses, it is quite possible to develop a variety of truss profiles, far greater than any other constructional material. While the main function of a truss is to essentially take all the loads at the points of application, and transfer them to supports as efficiently and economically as possible, the choice of profile also depends on architectural requirements consistent with loading conditions. In the design of trusses, several other factors also have to be taken into consideration such as any unbalanced conditions arising out of fabrication and erection, quite often a conflict may arise between the required architectural profile and the designed structural profile and, so the design must then introduce an economic balance between materials and workmanship, care being taken to keep the joints at a minimum as far as possible. All the typical profiles that are commonly used in the country can be classified and designed broadly under three main types: (a) pitched type (mono or double), (b) parallel-chord type (also known as flat type), and (c) bow string type. The usual span-depth ratio for these trusses are $L/4$ to $7L/10$ for mono pitched trusses, $L/8$ to $7L/20$ for double pitched trusses and $L/6$ to $L/10$ for bow string trusses and parallel-chord trusses. Only some general considerations are discussed here as more details and special types are available from several text books on timber engineering published in USA, European countries and Australia. In India, there are as yet no specific standards on trusses but a fair amount of literature is available from the Forest Research Institute, Dehra Dun; Defence Departments (MES) and some PWD organizations on typical designs of trusses. The Forest Research Institute has made some systematic studies on trusses using timber of different species and different type of joints from 3 to 16 metres span, for light, medium and heavy weight roofing material. Some structural forms developed in the Institute with small dimensioned timber are illustrated in Fig. 7 to 9.

A list of available designs are indicated in Appendix F. These designs can be obtained on payment from the Forest Research Institute.

6.1.2 *General Factor For Design*—The following check list in the order suggested helps to reduce the amount of work involved in designing trusses:

a) Choose the type of truss (truss profile) depending on architectural requirement and structural compatability and feasibility of fabrication and erection.

b) All the live loads acting on the truss should be carefully assessed.

c) All the dead loads including those due to roofing, sheathing, rafters, weight of truss, etc, should be computed.

d) The stresses in various members may be worked out.

e) The availability of species and grade of timber is to be examined with particular reference to the costs involved.

f) The size of the member required to carry the maximum stress due to worst combination of loads may be worked out.

g) The type of joints and connectors to be used should be determined on the availability of material and workmanship, and sizes of members determined above.

h) The joint has to be designed for carrying the maximum load at the joint and special care should be taken for members which take load at an angle to the direction of grain.

j) In the analyses of stresses in a truss or any framed structure some commonly accepted assumptions are to be remembered.

  1) When forces act parallel to long axis of a member it should be designed as a column or tension member. If there are lateral forces also on the member it should be treated as a beam under the action of combined forces.

  2) External forces are always assumed to act on joints at the point of intersection of the axes of the members. Resisting forces acting towards a joint induce compression and those acting away form a joints induce tension.

  3) Since a joint is in equilibrium, sum of all vertical components of all forces is equal to zero (that is, $\Sigma V = 0$) and similarly sum of all horizontal forces is zero (that is, $\Sigma H = 0$). Also the sum of moments of forces acting about the joint is equal to zero (that is, $\Sigma M = 0$).

  4) In view of the above, for determining the forces acting on each member of a joint, and so on the entire truss any of the following methods available in any standard text book on civil engineering or applied mechanics can be adopted as convenient: (i) trigonometric method (ii) moment method and (iii) the graphic method.

  (*see* Fig. 10 and example 4 in Appendix K for a simple trigonometrical method).

k) Some of the following experiences at the Forest Research Institute are useful in the design of trusses.

  1) An initial camber for short span trusses is recommended as 1/200 of the span. For longer spans this may be slightly

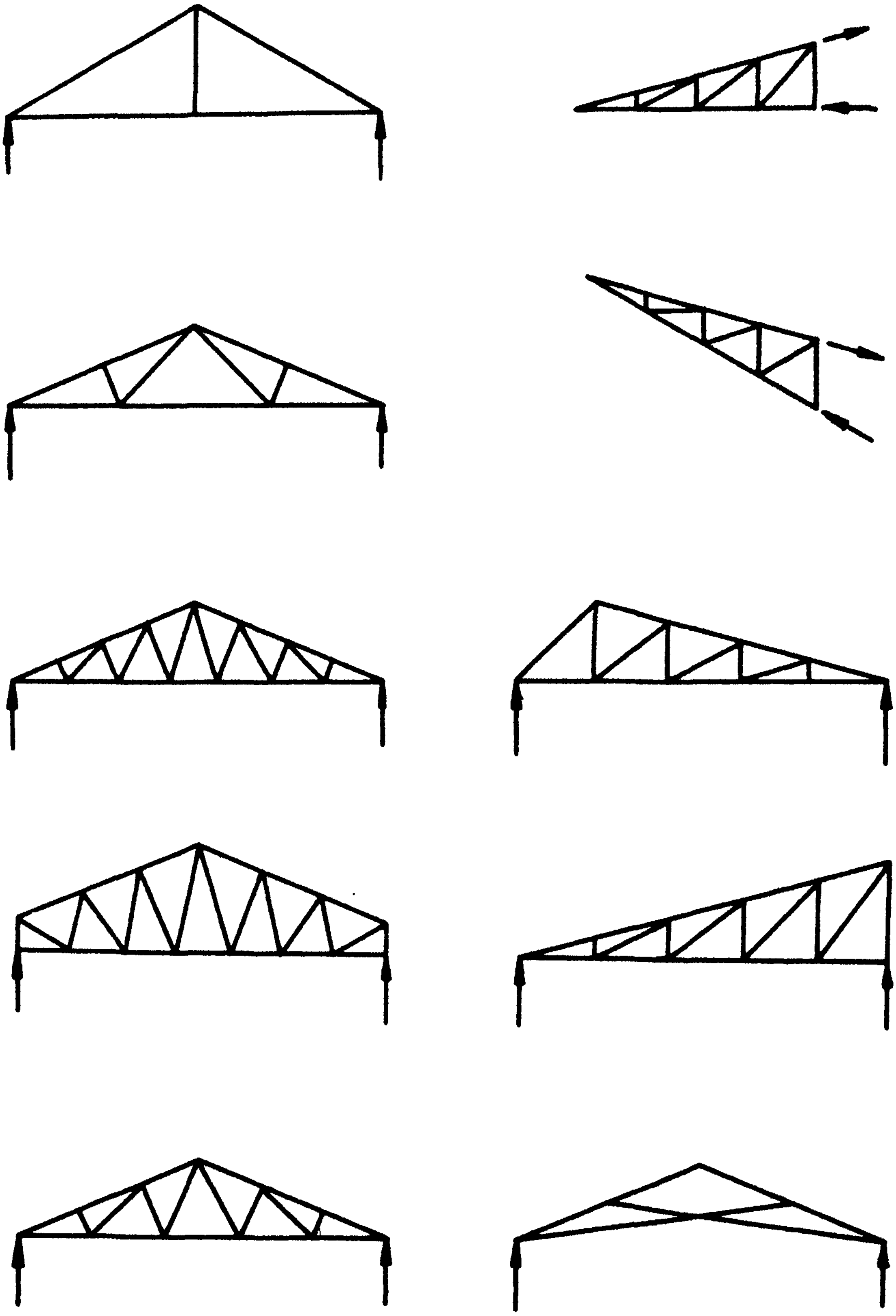


Fig. 7 Roof Trusses (*Contd.*)

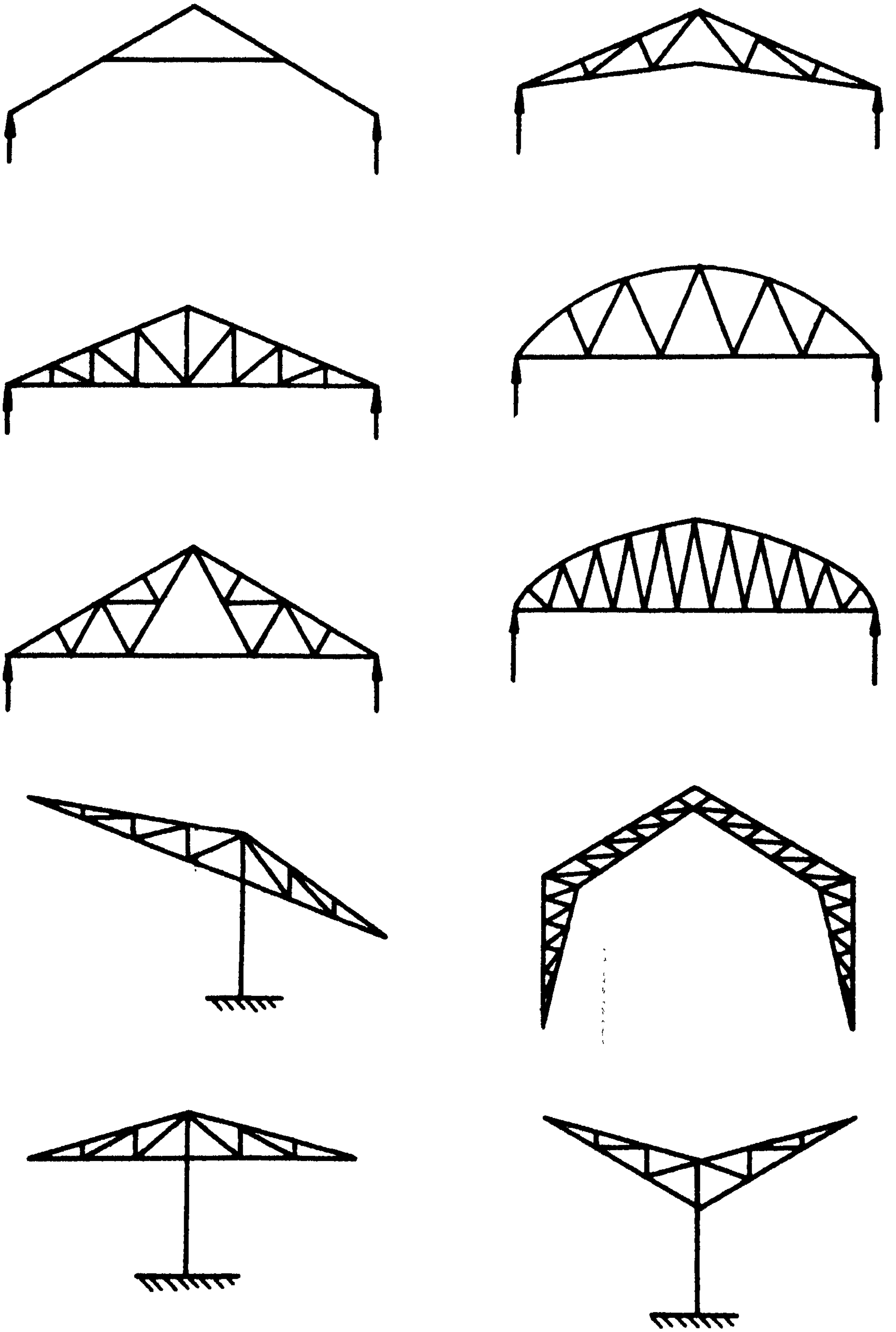


FIG. 7 ROOF TRUSSES

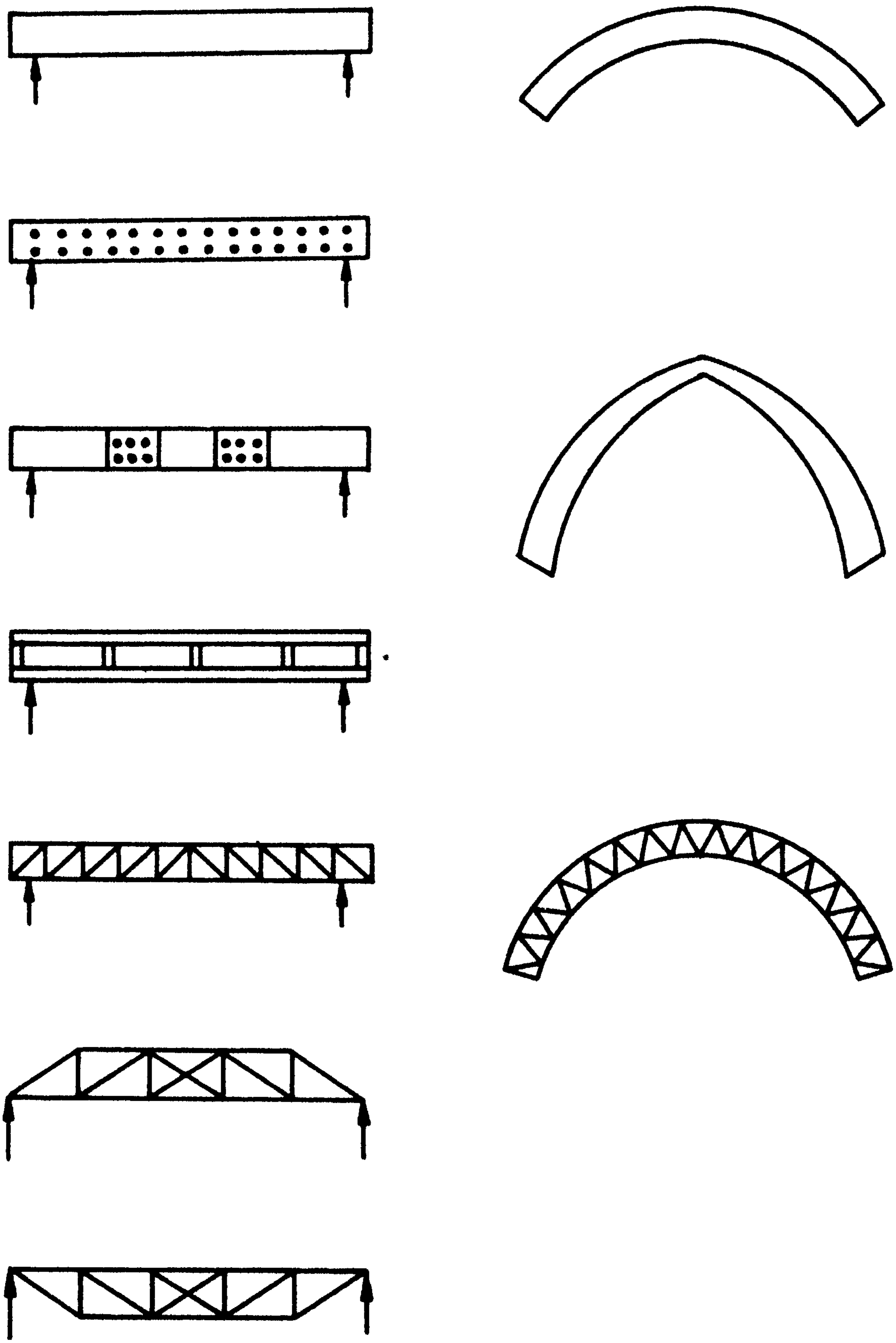


FIG. 8A. BEAMS, GIRDERS AND ARCHES

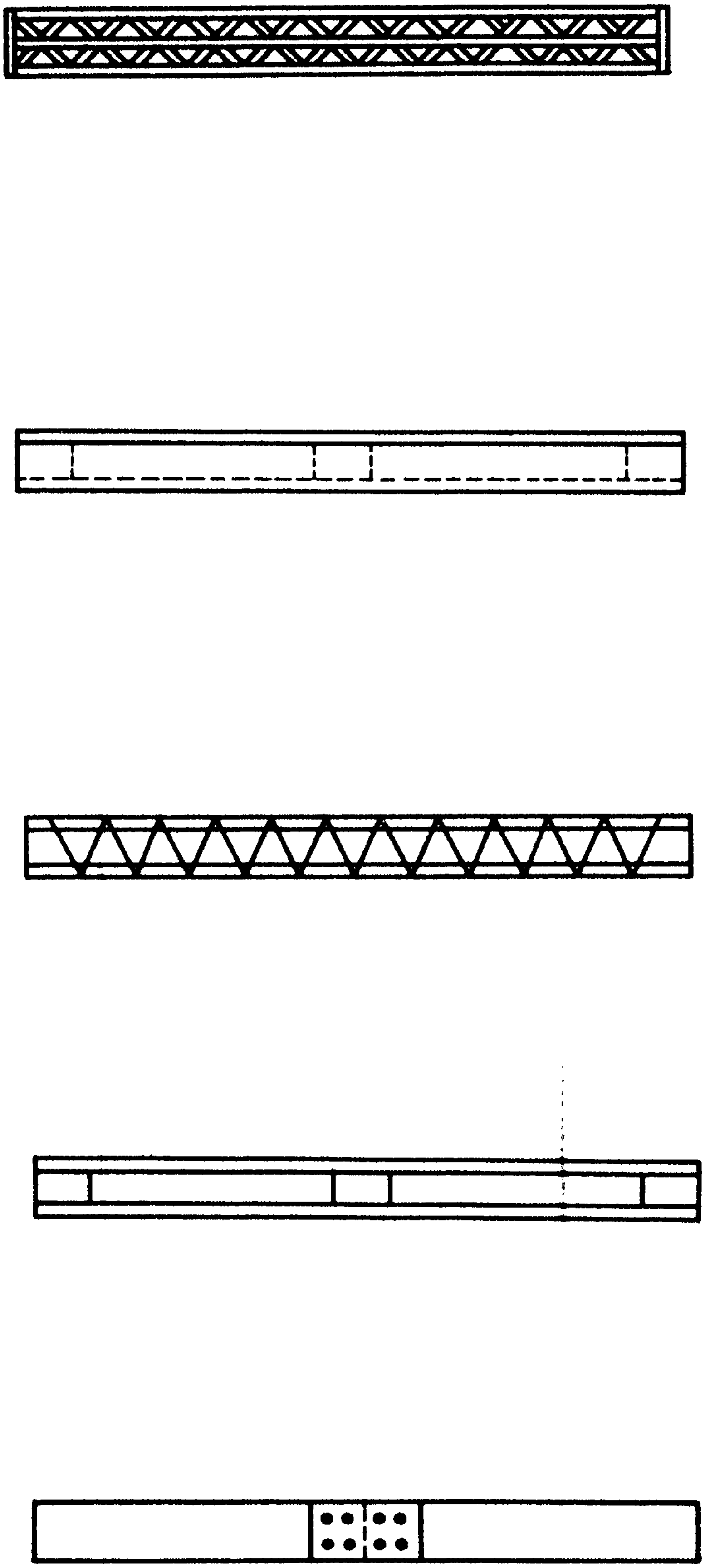


FIG. 8B COLUMNS AND STRUTS

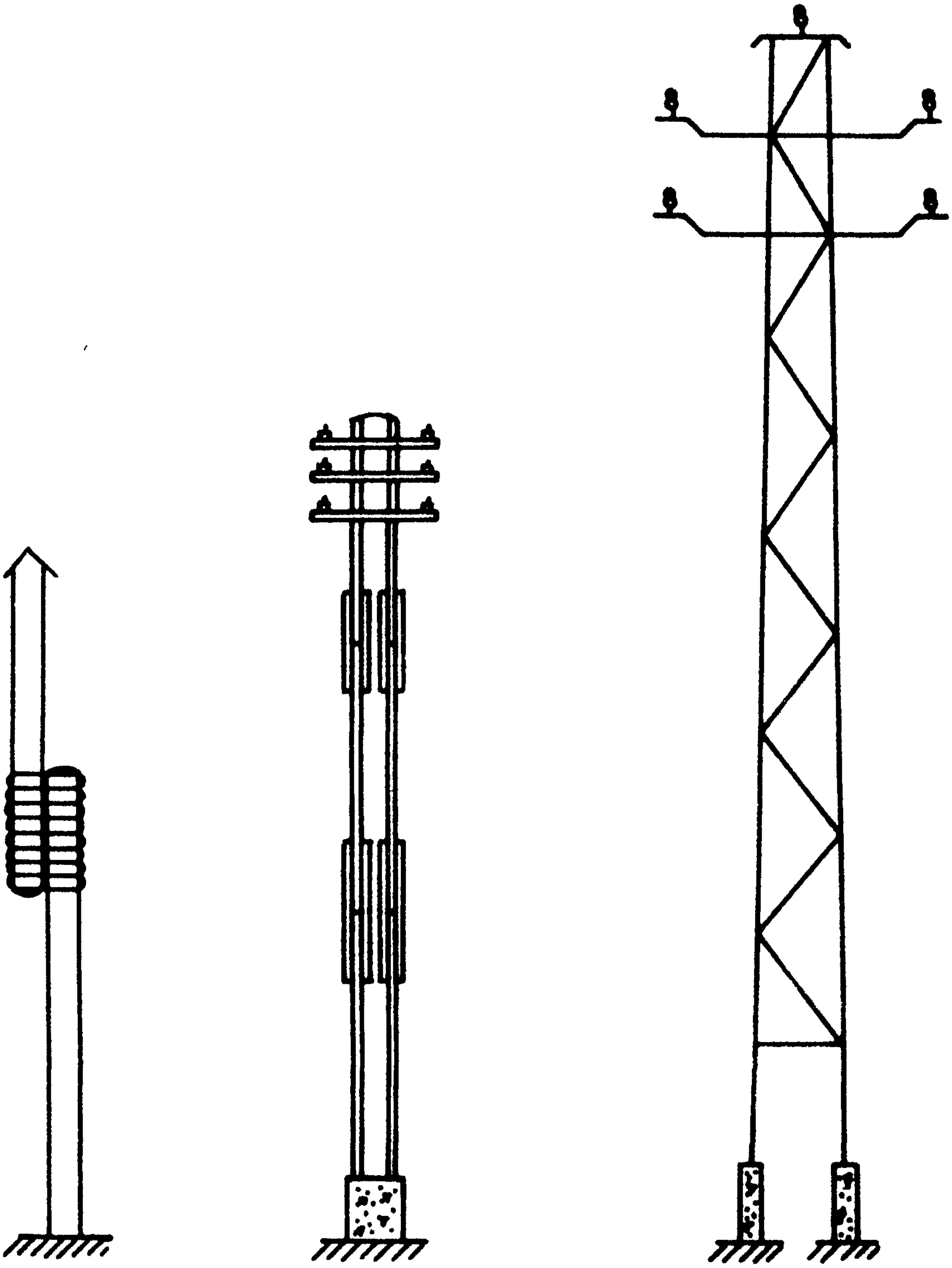


FIG. 9 ELECTRIC POSTS AND POLES

increased. If unseasoned wood is used the camber is recommended to be 1/100 of span (*see* NBC).

2) For different spans of trusses there is an optimum spacing of trusses for best economy. This is about 3 to 4.5 metres for spans ranging from 6 to 20 metres, and 5 to 6 metres for spans greater than 20 metres. Increase in spacing of trusses, reduces the overall cost which includes the supporting pillars also. The National Building Organisation (India) in its Handbook for Building Engineers suggests a formula for economical span L (length of purlins) in terms of modulus of elasticity (E), moment of inertia of the section (I), and total loads per centimetre length of the purlin (W) as:

$$L^3 = \frac{0.384\,EI}{W}$$

but neither this seems to have been incorporated in Indian standards, nor widely used.

3) For three-metre spacing of trusses, jointed purlins will be quite economical. For greater spacings trussed purlins or triangular purlins are recommended.

4) While the purlins are to be placed at requisite node points, for practical purpose a shift of 10 cm on either side of the centre of node will not seriously affect structural safety.

5) Strength-reducing defects should be avoided as far as possible at the joints, and at load transmission points. Stressed members may be allowed permissible defects.

6) Wood-working operations should ensure that no unaccounted stresses come into play, particularly at the joints.

7) Undue deflections which may create unaccounted stresses, may be minimized by using lower safe stresses, larger sizes, lessening the joints, and using fastenings with low slip characteristics.

8) In all cases where the designer is not fully satisfied with the details of calculations to meet a particular requirement, he should be particularly careful to ensure that the strength and stiffness of the truss as a whole is adequate and should prefer a prototype test (*see* **7.2** and **7.3**).

6.1.3 *Joints in Trusses* – It is obvious, the joint in a stressed member being the weakest, its design should ensure complete safety not only in the use of truss as such and its load bearing capacity, but also take into consideration the limitations of carpentary practices involved and the probability of timber swelling and shrinking, the development of cracks, splits, etc, and many other factors which may reduce the effectiveness of the joint. There are many types of joints, which can be broadly classified as: (a) mechanical joints which are effected through fasteners, and (b) glued joints which ensure permenent rigidity if properly done. Of the latter the finger joints are coming into prominence more recently (*see* **6.3**). Many of the housing type joints like mortise and tennons are generally avoided these days. Instead,

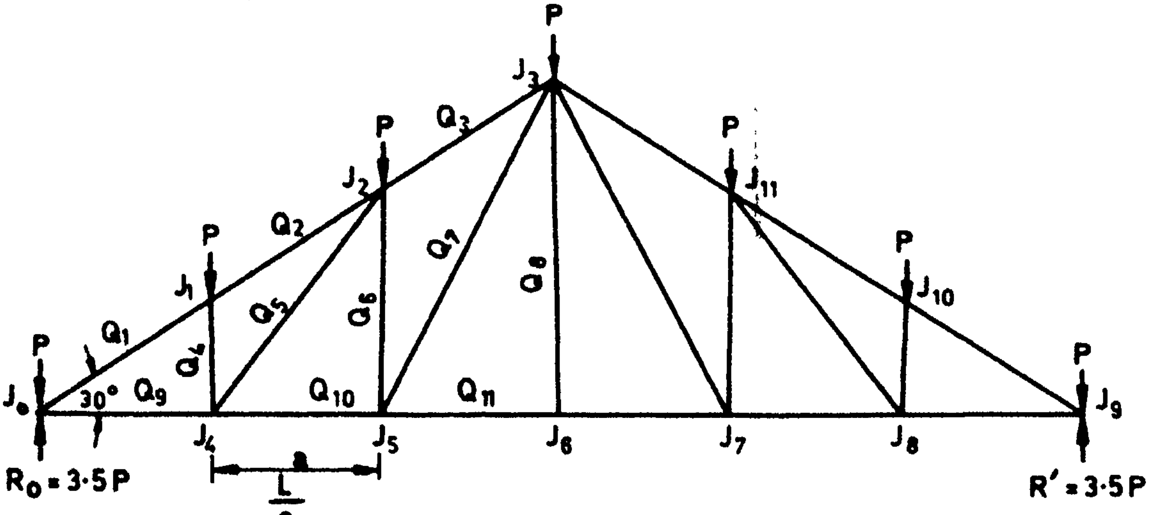


FIG. 10 ANALYSIS OF A SIMPLE TRUSS

dowels, bolts, straps, spikes and nails are used for the mechanical type joints. Sometimes glued and nailed joints are used. Generally the cutting of timber is now limited to notching or preboring, where necessary, thus developing the lapped or half-lapped joints and using fasteners. The design and use of fasteners and joints are discussed in **6.3**. The NBC gives requirements of spacing nails in structural joints, but some of the individual specifications for special constructions indicate typically accepted joints, for example, IS : 3670-1966 prescribes jointing details for floor boards and IS . 2366-1963 for structural purposes, etc. Considering the special case of nail-jointed truss construction, NBC recommends that the total combined thickness of the gussets or splice plates on either side of the joint in a mono-chord type construction should be equal to, or more than one and a half times the thickness of the main members subject to minimum thickness of 258 mm of individual gusset plate. The total combined thickness of all spacer blocks or plates or both including outer splice plates at any joint in a split chord type construction should be not less than one and a half times the total thickness of all the main members at that joint. In passing, mention may also be made here of IS : 3845-1966 which mainly deals with joints for furniture but the general precautions mentioned therein will also be applicable to some types of structures, particularly light constructions. Wherever transmission of load through a bearing area, particularly where washers of metal plates are used, the modification factors discussed in **5.2.6** should be kept in mind.

Eccentricity in joints should be avoided, particularly in heavy stressed members, if however eccentricity comes in the design or fabrication, the effect of induced moments should be taken into consideration when calculating the fibre-stresses.

6.1.4 *Deflection in Trusses* — The deflection in a truss is caused by: (a) strains in members which may be due to compression or tension, and (b) slips in joints. These may be computed separately for each member and for each joint, and the total may be computed. The American Institute of Timber Construction Standards quote some empirical formulae for calculating deflection of different types of trusses, but these are highly empirical and independent of the size of members, the stresses that come on the same, and the type of joints. The formulae are given below:

a) For symmetrical flat and pitched trusses :

$$\Delta = \frac{L^2}{4290H}\left[\frac{L}{26.6} + 1\right], \text{ and}$$

b) For bowrstring trusses

$$\Delta = \frac{L^2}{1900H}\left[\frac{L}{6} + 1\right]$$

where

Δ = total deflection in metres,

L = span of the truss in metres, and

H = height of the truss in metres.

6.1.5 From the limited discussions above, it may be seen that although there exists in India some experience of designing, fabrication and erection of a few timber trusses of different types, there is still considerable scope for engineering investigations in studies relating to trusses and their standardization. As examples of these aspects, mention may be made of analysis of stresses at different mechanical and glued type of joints, development of modification factors for the same for calculating stresses; quality control requirement for such joints; development of design coefficients for various members for ready evaluation of stresses in them, standardization of typical trusses using different groups of species and grades, and development of codes for using different types of timber trusses under different conditions, etc.

6.2 Special Constructions

6.2.1 The general aspects of timber design in so far as they relate to solid structural components and simple trusses have been dealt in the earlier sections. The current practices as reported in various Indian standards and other published literature has been covered, and wherever considered necessary, the practices as exist in other countries have also been briefly mentioned. In the foregoing sections, it is proposed to deal with only some specific areas of timber engineering for which there exist already some relevant Indian standards. As reference to the corresponding standard is always desirable, only the most important aspects are discussed below.

6.2.2 *Timber Floors (IS : 3670-1966)*

6.2.2.1 The specification on timber floors covers only the fabrication and laying of timber floors and their relevant components. The specification provides also for special contractual information to be exchanged as a pre-condition for satisfactory laying of floors. This includes not only the time schedules for various operations but also the quality of materials, the design data, the required processing of the materials before the floor is laid out, and also subsequent dressing operations, filling with floor seals, and further treatment required on flooring, when completed.

6.2.2.2 Five types of floors have been recognised in IS : 3670-1966. They are briefly described here. The main floor boards recommended are to be 2.5 to 4 cm thick and not greater than 15 cm wide and 3.5 metres long. Several types of end-to-end jointing of boards are recommended according to economy and efficiency, though no specific details are indicated.

a) *Single joisted floors* — These may be either at ground level or upper floors, with floor boards laid directly on bridging joists. The maximum span of the joists should not be more than 3.5 metres and the width should not be less than 5 cm. The ratio of depth-to-breadth should be between 3 and 4 and it should be designed as a beam with deflection not more than 1/360 of span. At the ground level a minimum of 30 cm floor space is required to be provided beneath the floor and also proper ventilation of 22 to 85 cm^2 depending on extreme dry to highly humid conditions. In the upper floors, the resting of joists should be on wall plates, and when covered, should be well treated and protected to prevent decay. If the spacing between joists is more than 2.5 metres, they should be herring-bone strutted by 3 × 5 cm members. In case of heavy floors, solid type strutting may be employed with members of ¼ depth of the joists, and breadth equal to 1/3 or 1/4 of the depth.

b) *Double joisted floors, having the bridging joists supported on binders* — These are adopted where the span of bridging joists is more than 3.5 metres but less than 5 m. The binders supporting the bridging joists may have a maximum span of 5 m and they should be well supported.

c) *Triple joisted floors or framed floors* These are adopted when the span of binder exceeds 5 metres but not more than 10 metres. Hence they are recommended to rest on girders. Although it is said in the specification that jointing between binders and girders should be by tennons, and is indicated by a rough diagram, it appears there can be considerable flexibility in construction techniques, depending on loads and the sizes of the girders available. Also some limitation is placed on the spacing of girders but this is a factor which may depend on the length of binders which according to the specifications may vary from 5 to 10 metres.

d) *Solid timber floors* — These consist mainly of a cement concrete sub-floor of 5 to 7.5 cm thickness embeded with wooden fillets of 12.5 × 4 cm on which the main wood floor boards of atleast 2.5 cm thick are placed.

e) *Purpose made floors* — These are generally designed for skating rinks, and indoor games like badminton and squash.

6.2.2.3 IS : 3670-1966 does not deal in detail any particular design aspects. For floor boards it recommends species mainly on the basis of suitability figures of 'hardness' of timbers compared to teak as 100 (*see* **3.1.4** and Table 7). The range of the suitability figure chosen is from 55 to 135. It is further claimed that in the recommendation of the species due consideration has been given to other indices such as 'shock-resisting-ability', 'strength as a beam' and 'retention of shape'. In this connection, if a choice of species is to be made at all, that is, particularly when species as such are intended to be used, then it would have been more appropriate to arrive at a composite index figure by suitable combination of the properties, giving due weightage to their relative importance as discussed in **3.1.4**. It has been recommended further that for girders, binders, and bridging joists, all species of Group C may be used up to 6 metres span, all species of Group B for spans between 6 and 12 metres, and all species of Group A for spans of 12 metres and greater (*see* **5.1.1** and, Appendix B of IS : 3670-1966). There does not seem to be any specific rational behind these recommendations. In fact, species of higher strength (that is, Group A can also be used for shorter spans with increased economy and safety, for timber is sold not according to their weight which in turn reflects its strength, but according to dimensions). Longer dimensions cost more. Except the popular species, most of other species have roughly the same price in market. It may be noted that in Appendix C of IS : 3670-1966, a minimum values of 56 246 kg/cm^2 of modulus of elasticity, and 85 kg/cm^2 for extreme fibre stress are recommended for timbers for various purposes. But obviously this serves only as a further guide in selection of species, and appears somewhat redundant in the context of limitations already placed on surface hardness, and also in the context of sufficient variation having been permitted in the dimensions of various members of the floor, depending on commonly assumed loads and other requirements.

6.2.3 *Wooden Stairs in Houses (IS : 1674-1973)*

6.2.3.1 This specification deals with material, constructional details of interior wood stairs for houses, and does not cover the design, construction of monumental, decorative and special types of wood stairs for which sufficient number of advanced books on timber architecture are available. The general arrangements recommended are as follows and these have been aligned with the relevant provisions in the NBC.

a) The material can be any of the species recommended in IS : 399-1963 for constructional purposes. It would have been preferable if at least the range of hardness of the species is limited similar to floors given in IS : 3670-1966 for this purpose also. Similarly, if plywood is used, it is recommended that it shall conform to BWR type of IS : 303-1975 in a general way.

b) The head room should be at least 2.2 metres from ceiling or soffit to the pitch line with a clearance of atleast 1.5 metres at right angles to the line.

c) The pitch should not be more than 37°.

d) The going (g) should not be less than 25 cm and the riser (r) not more than 19 cm and both should be same for all steps in any one flight. The empirical rules governing the above are: (1) $2\ r + g > 530$ mm and < 630 mm. and (2) $r \times g > 40 \times 10^3$ $< 50 \times 10^3$ mm^2.

The number of risers in any one flight should not be more than 12. After considerable discussion, the committee concerned with the preparation of the standard, came to the conclusion that physical exertion in climbing the steps relates to the dimensions of each step and the number of steps rather than to the total height of the flights.

e) Treads should be less than 27 cm in width and their nosing should be properly rounded off with its projection not less than 15 mm and not more than its thickness, beyond the face of the riser.

f) Clear width of stairs between inside to inside end strings shall not be less than 1.0 m and the width of landing should not be less than the width of the stairs.

g) The vertical height from the pitch line to the top of any sloping hand rail should not be less than 1.0 metre.

h) Winders are generally to be avoided but provided there should be three for a quarter of space and six for half the space.

6.2.3.2 IS : 1634-1973 gives further general guidance on constructional details about treads, risers, strings, landings, newels, hand-rails and balustrades, and also about finishing. This guidance is based on general good carpentary practices, and cannot be taken strictly as a building code requirements or standard practices. However references to IS : 3670-1966, IS : 5389-1969, IS : 2338 (Part 1)-1967 and IS : 2338 (Part 2)-1967 are recommended to be made for satisfactory performance and appearance of the stairs. It appears that with the incoming of several other types of alternate wood based materials, like compregnated woods, veneered particle boards, plywoods, etc, there is a further scope of developing the designing and construction of wood stairs.

6.2.4 *Hardwood Parquet and Wood Block Floors (IS : 5389-1969)*

6.2.4.1 This specification deals only with fabrication and laying of parquet and wood block floors but mosaic parquet flooring has not been covered. Parquet has been defined as aggregate of parquet strips assembled in horizontal plane forming the upper part of a floor. Regular patterns of parquet floor are arranged in large areas to form panels and laid in symmetrical designs on a sub-floor of timber boards. In the execution of these type of floors the important factors to be considered have been recognized as: (a) the floor to be covered, (b) the type of timber flooring including the species and the grade, (c) the thickness of flooring and relationship of finished surface with reference to a datum, (d) constructional aspects including any services passing, type of under lay, fixing techniques, and (e) treatments like damp proofing preservative treatment to species, treatment of skirtings, treatment of junction with adjacent flooring, dressing and polishing, etc.

6.2.4.2 In discussing the various species suitable for the purpose, suitability figure of hardness compared to teak as 100 (*see* **3.1.4** of IS : 5389-1969) has been chosen as the main criteria and it is further recommended in the specification that species of different hardness should not be used as there would be a likelihood of uneven wear in due course. However it would have been evolved taking into consideration the shock resisting ability and retention of shape also. But it should be kept in mind that in evolving such types of floors, different naturally coloured species are generally selected to give different beautiful patterns. The timbers used should definitely be seasoned and processed well in accordance with IS : 1141-1973 and IS : 401-1982, and the whole floor should be protected against termites, and other wood destroying agents. Also moisture should be prevented by damp proof layers according to IS : 1609-1976.

6.2.4.3 In the code of practice for laying of parquet and wood block floors, the thickness of floor blocks and parquets are recommended to be from 25 to 40 mm. which is a very wide range but in practice, to reduce the costs and working operations 25 mm is the most common thickness. The other components of floors are recommended in IS : 5389-1969 as follows:

a) *Sub-floor* — 50-75 mm thick; to be well planed and all loose boards to be made firm. Sometimes this sub-floor can also be of cement concrete.

b) *Panels* — Generally square pattern of 30 to 35 cm side but occasionally panels of size used are as small as 15 cm or as large as 90 cm. Panels are placed in position with mastics (IS : 3037-1965).

c) *Battens* — Properly square edged, generally 15 to 50 cm in length 5 to 10 cm in width, and 5 to 10 mm in thickness are used.

d) *Border* — A design, different from the main, is adopted up to a width of about 60 cm. In addition to beauty this will set the required geometry of the main floor.

e) *Wood block floors* — These are to be properly grooved, tongued, and fitted either through battens or directly on mastic or bitumen in semi-fluid condition. The blocks are usually of sizes 25 × 7.5 cm to 30 × 7.5 cm with thickness of 2.5 to 4 cm approximately.

6.2.4.4 After laying the various components of floors, all pores and holes appearing on the floors should be sealed with proper floor seals, and the surface should be made smooth preferably by power driven sanding machines. The floors should be also polished by traditional oils, waxes, synthetic resin polishes, and should be frequently maintained on the same lines (*see* 9). The cost of such flooring is an important factor and should be viewed against the background of the architectural requirements and purposes intended in different halls, auditoria, etc. It may be interesting to note that in 1960-70, the floors laid in different parts of the country costed between Rs. 30 and Rs. 90 per square metre depending on species and designs, etc. New types of material like irradiated woods, compregs and laminated products are gradually coming into use in several parts of the world.

6.2.5 *Roofing with Wooden Shingles (IS : 2700-1964)*

6.2.5.1 This specification deals with laying of wooden shingles for roof covering. For laying and fixing of other roof coverings (slates), reference may be made to IS : 5119 (Part 1)-1968. A shingle has been defined as thin flat tapering rectangular piece of wood, 30 to 40 cm long, and 12 to 15 cm wide used as a roofing tile, obtained either by sawing or by splitting. Currently the specification recommends species of high decay resistance, for heartwood and low shrinkage as suitable for shingles, but in the suggested fifteen species, there are some of lower durability also which can be used after proper treatment only. Well seasoned and treated species are reported to have given quite a long life. However, as these are exposed to weather, periodical maintenance and replacement of any decayed material would be necessary.

6.2.5.2 The following are some of the important design considerations:

a) Wooden shingles may be supported on battens over purlins and rafters over roofing sheets like GI sheets or timber roofing boards, (particularly in very damp and heavy rain fall areas). The load of shingles along with only battens are taken as 20 to 25 kg/m^2 for all design purposes. Where necessary, this can be worked more accurately from the specific gravity and moisture content of the species employed. The moisture content of all timber used should be in accordance with IS:287-1973 for different zones of India.

b) The pitch of the common rafter or surface on which shingles are laid, should not be less than 35° and this should be increased in elevated sites or areas of heavy rain fall.

c) The battens generally of 5 × 2.5 cm supporting the shingles should be spaced equally at distance of about 1/3 the length of the shingle (that is, 10 to 13 cm for length of shingles of 30 to 40 cm). The spacing of rafters should not normally exceed 60 cm unless the battens also are designed for loads.

d) At every section in the roof area the shingles should be atleast three deep course of shingles (except the bottom two courses) and they shall be fastened to battens by standard MS nails (IS : 723-1972) of 2.24 mm shank diameter and 4 cm length. The distance of nails from the butt end of the shingle should be 1 to 1.5 cm more than exposed length of the shingle, and not more than 2 cm from the edge. Each course of wooden shingles should be overlapped by another course such that only 1/3 of the length of the shingle of lower course is exposed and the remaining two-thirds is overlapped. In each horizontal course the shingles should be atleast 3 to 6 mm apart for shrinkage and swelling.

e) Each successive course of wood shingles should be break-jointed; that is, the inter-shingle gaps in the successive courses should not be in the same line but should be off set by about 4 cm. The general arrangement of roofing with wooden shingles may be seen from Fig. 1 and 3 of IS : 2700-1964.

6.2.6 *Timber Ceilings (IS : 5390-1969)*

6.2.6.1 This specification is a code of practice for fabrication and laying of timber ceilings and their relevant components. Two types of ceilings have been recognized. (a) the ceilings when the distances between trusses are not greater than one metre and the truss acts as truss rafter, and (b) the ceilings when the distance between the trusses is more than one metre. In the above specification about 24 species have been selected as suitable for ceiling and no special criteria has been mentioned. However, since they are to be fixed from bottom side it is considered that comparatively light timbers would be preferable. Sometimes architectural designs may be required in the ceilings for which easy wood working qualities of the species would be an added advantage.

6.2.6.2 In the design and execution of ceilings while keeping IS : 883-1970 in view some factors have been indentified in the code as important. These are: (a) species and grade of timbers; (b) types of ceiling and its thickness, its level to a datum and its fixing; (c) type of underlay, if any; (d) preservative treatment of timbers; (e) treatment of junctions; (f) services passing through ceiling, if any; and (g) dressing, painting or polishings, etc. The required moisture content is recommended to be based on IS : 287-1973 for different zones of India. The recommendation with regard to seasoning and preservation are to be as usual in accordance with IS : 1141-1973 and IS : 401-1982. The usual protection against termites and dampness also is recommended. In addition to the above, the following specific recommendations are made with regard to sizes and constructions:

a) Timber plants used should be between 15 and 20 mm thick, and not more than 100 mm wide. The longitudinal edges of planks may be jointed by any conventional method as: (1) butt and beading type, leaving a small gap between the edges and using a bead of about 30 mm wide; (2) overlap type such that each plank overlaps the adjoining plank by about 15 mm keeping alternate planks in the same level; (3) half-lap edge joint with the lap of about 15 mm wide; and (4) tongue and groove joint with about 10 mm tongue.

b) With regard to fixing, three types are recognized as follows: (1) sloping ceilings are fixed immediately below the roofing, usually just above the purlins; (2) horizontal closed ceilings are fixed on the underside of floors, and roof-framings, or sometimes independently, when the roof frame is too high and lower ceiling levels are to be adopted; and (3) horizontal open ceilings are fixed below roofs and floors by nailing suitable fillets of 4 × 4 cm cross-section to the bridging joists or tie beams, etc. Open ceilings have the advantage of provision for sound proof material in the hollow spaces.

6.2.7 *Bridge Constructions*

6.2.7.1 Although there are no prescribed national standards and codes for timber bridge constructions in India, there is a fair amount of experience in the country in the design of bridges. One of the earliest publications on the subject of highway bridges was by Dr S. Kamesam. Basing his designs on standard PWD loadings, he had constructed several bridges ranging from 2.5 to 21 m with both treated sawn timber and also round timber for the standard widths, namely, 4 and 5 m. Forest Research Institute has developed various types of bridges from spans of 3 to 18 metres for IRC Class B loading of PWD standards. Several types of bridges, including pantoon bridges, have been developed by defence services in India for crossing rivers, and narrow valleys in hill regions. However, these experiences have neither been standardized nor codified at national level so far, and it may be worth while to coordinate these designs and arrive at some uniform basic design considerations for bridges.

Timber bridges are broadly divided into two types: (a) the trestle type, and (b) the truss type bridge. In India mostly the truss types exist. In other countries bridges of 80 to 100 metres spans have been developed using metal connectors and by glued laminated constructions. So far, it appears that general guidelines of design in IS : 883-1970 have been followed for bridge beams, girders and trusses. Where necessary increased consideration of safety have been specifically provided on local circumstances. Sometimes the designs were checked by actual loading tests, and sometimes by testing reduced size models in structural laboratories. It is needless to point out that in such types of constructions as bridge constructions, the joints and fasteners have always attracted greatest attention. The economy of the bridge depends not only on the initial cost and annual maintenance, but also on the expected life of the bridge. Well treated timbers may preserve a bridge for much longer time than usual, but the life expectancy should be based on consideration when the structure may become obsolete either on account of new types of traffic or on account of new materials of construction. As the bridges generally remain exposed to weather, it is necessary to use durable or well treated timbers and adopt special maintenance precautions such as painting with moisture resistant oils or paints.

6.2.8 *Lamella Construction*

6.2.8.1 Recently some attempts have been made for developing lamella roofs by using relatively short curved timber planks bevelled and bored at their ends and joined together by bolts at an angle through another member bored at its centre to form a curved network of stiffenned timber members. These structural elements are decorative in themselves and so it has attracted the architectural requirements mostly for assembly halls, churches, pavilions and restaurants, etc. Depending on the span of the arch, and the loads on the roof, the individual lamella units can be easily fabricated in workshops and the erection is carried out easily at site, giving adequate protection at the ends of the arch to prevent its slipping laterally. The thrust of the roof is taken either by tie rods, or buttresses, or concrete pipes. The rise of the arch generally varies from 1/5 to 1/7 of the span.

6.2.9 *Earthquake Zone Constructions*

6.2.9.1 Not much information is available on any special types of timber constructions for earthquake zones, but it is advisible for the designer to take into consideration the relevant clauses on seimsic loads recommended in NBC. The vibrations caused on the structure may be resolved into three perpendicular directions and the design may be made safe for the vibration sway and damping in all directions simultaneously. The predominant direction of vibration is considered horizontal. Wherever earthquake forces are considered along with other normal design forces, the permissible stresses in materials (in the elastic method of design) may be increased by one-third. However, it should be remembered that timber can normally develop under dynamic conditions twice the strength required under static conditions, but the same may not be exactly true of the joints. For the purpose of determining seismic forces, the country is classified into five zones with horizontal seismic coefficients of values 0.01, 0.02, 0.04, 0.05 and 0.08 (*see* IS : 1893-1975). Vertical seismic coefficients, wherever necessary, may be taken as half of the corresponding horizontal coefficient. The choice of a value for damping coefficient of timber structure is a matter of judgement, but a damping coefficient of 2 to 5 percent of critical value is suggested in NBC.

6.2.10 *Fire-proof Construction (NBC Part IV, IS : 1642-1960 and IS : 1643-1960)*

6.2.10.1 It is now well recognized that fire hazard is a potential danger to any type of building with any material. What is more important is to prevent the causes of fire and its spread than choose a building material on the basis of its resistivity to fire or to reject a material because of its combustibility. It has been the common experience that in the case of serious fires to buildings, in the various types of efforts to control the same, the wood material can be salvaged for re-use, and part of the money at least is recovered, whereas most of other materials are destroyed completely with no value for re-use at all. However in all cases of precautions against fire, the intention in the design is to save life in preference to property and so the time taken for the occupants to escape is most important. British standard classifies building materials into four classes depending on their fire-resistivity and flame spread characteristics. Most of the wood and wood products come under Class 3, that is, surfaces of medium flame spread. Low density woods and insulation boards are classified as Class 4 (that is, surface of rapid flame spread). Wood wool cement boards are classified Class 1 (that is, surfaces of low flame spread). There does not seem to be any such standard classification of wood and wood products in India as yet. However, IS : 1643-1960 and NBC (Part IV) deals with fire protection in greater detail and the general clauses are applicable to timber structures also.

6.2.10.2 As a result of some laboratory studies on fire resistance of wood, D. Narayanamurthi and G. Gopalachari (Indian Forest Bulletin No. 118, 1943) came to the conclusion that heavier timbers and timbers with tylosses offer more resistance than timbers free from tylosses, as the vessels plugged with tylosses offer more resistance to the movement of gases through the timber. This is taken as an indication that timbers which are difficult to treat also offer more resistance to spread of fire. Other properties which affect the fire resistance are the thermal conductivity and specific heat which determine the rate of change of temperature. Some of the structural species arranged in order of their resistance to fire, calculated from their rate of burning curves, are the following:

1. *Diospyros* spp
2. *Hopea parviflora*
3. *Hardwickia binata*
4. *Chloroxylon swietenia*
5. *Eucalyptus globulus*
6. *Anogeisses latifolia*
7. *Quereus* spp
8. *Acacia arabica*
9. *Shorea robusta*
10. *Terminalia tomentosa*
11. *Stereospermum chelonoides*
12. *Bichovia javanica*
13. *Albizzia lebbeck*
14. *Pterocarpus dalbergiodes*
15. *Terminalia paniculata*
16. *Carapa moluccensis*
17. *Pterocarpus marsupium*
18. *Albizzia odoratissinna*
19. *Dipterocapus* spp
20. *Terminalia belerica*
21. *Dalbergia sissoo*
22. *Tectona grandis*
23. *Lagerstroemia* spp
24. *Juglans regia*
25. *Artocarpus hirsuta*
26. *Cedrela toona*
27. *Hymnodicton excelsum*
28. *Adina cordifolia*
29. *Caloplyllum tomentosum*
30. *Terminalia bialata*
31. *Schima wallichi*
32. *Morus* spp
33. *Pinus roxburghii*
34. *Mangifera indica*
35. *Cupressus torulosa*
36. *Terminalia myriocarpa*
37. *Picea morinda*
38. *Pinus excelsa*
39. *Anthocephalus cadamba*

The trade names and local names of the above species are given in Appendix G.

6.2.10.3 One of the methods used in fire-proof construction is to treat the wood with appropriate fire retarding chemical, (*see* **4.4**) depending upon the species and the nature of hazard likely to arise. Apart from such treatments discussed therein, there can also be a possibility of providing in the structure, some systems to prevent the spread of the flames. One way is to know the rate of charring of surfaces and to calculate safe dimensions to withstand the load, for people to escape in time. Another way is to identify spots of possible start of fires and provide fire stops to prevent the spread of fire. The greater danger of fire being at joints and connections which may induce undue twisting moments (particularly if they have metal components), it may be possible to design such joints either far away from the source of fire and the charring line, or to protect the joint externally by material of higher fire resistance or low combustibility. The engineer may also design the joint with increased net section or by collaborative tests under conditions of anticipated hazards.

6.2.11 *Bolts and Nail Jointed Constructions (IS : 2366-1963, IS : 4983-1968 and NBC)*

6.2.11.1 Of all types of jointed constructions in wood, the nail jointed construction has made rapid strides in the country as it was always necessary to make use of small dimensioned stock to keep the economy at lower levels. This subject on design aspects has been discussed in greater detail under **6.3**. Here only some special considerations that go into the constructions have been discussed. The nail joints can be used for butt joints or lap joints either in mono-chord construction or in split-chord constructions. At present only a few species have been tested for strength and these have been recommended in IS : 2366-1963 for permanent and temporary constructions.

6.2.11.2 Some important aspects on the fabrication of nailed constructions are discussed below:

a) The dimension of members should be within the following range (*see* IS : 2366-1963 and and NBC)

Thickness of members	: 15 to 100 mm
Width of members	: Normally should not exceed eight times the thickness.

In the case of lap joints minimum thickness of thinner member should be atleast 2/3 thickness of thicker member, and in case of butt joints, minimum thickness of splice plate members should be 3/4 times the thickness of main structural member.

b) Preferably there should be no lengthening joint at the nodel point and there should preferably be only one such joint, at any rate, not more than two between two nodal points.

c) The total combined thickness of the gusset or splice plates (in a monochord type construction) or of spacer blocks and plates in a split chord type should not be less than one and a half times the total thickness of all main members. The total combined thickness of all spacer blocks or plates or both at any joint in a split chord type construction should not be less than one and a half times the total thickness of all main members at that joint.

d) The diameters of nails should be between 1/6 and 1/11 of the least thickness of member and they should be preferably galvanized.

e) A camber of not less than L/360 should be provided in the lower chord of nail jointed timber truss for permanent constructions and *L*/200 for temporary constructions using seasoned wood and *L*/100 for unseasoned or partially seasoned wood.

f) All nails should be so arranged as to avoid undue splitting of the wood. The end distances, edge distances and spacings should be generally as given below and also illustrated in Fig. 11 to 13 more clearly for lengthening and node joints.

Spacing	*Stress in the Joint*	*Requirement*
End distance	Tension	12 *d*
	Compression	10 *d*
In the direction of grain	Tension	10 *d*
	Compression	5 *d*
Edge distance		5 *d*
Between rows of nails perpendicular to the grain		5 *d*

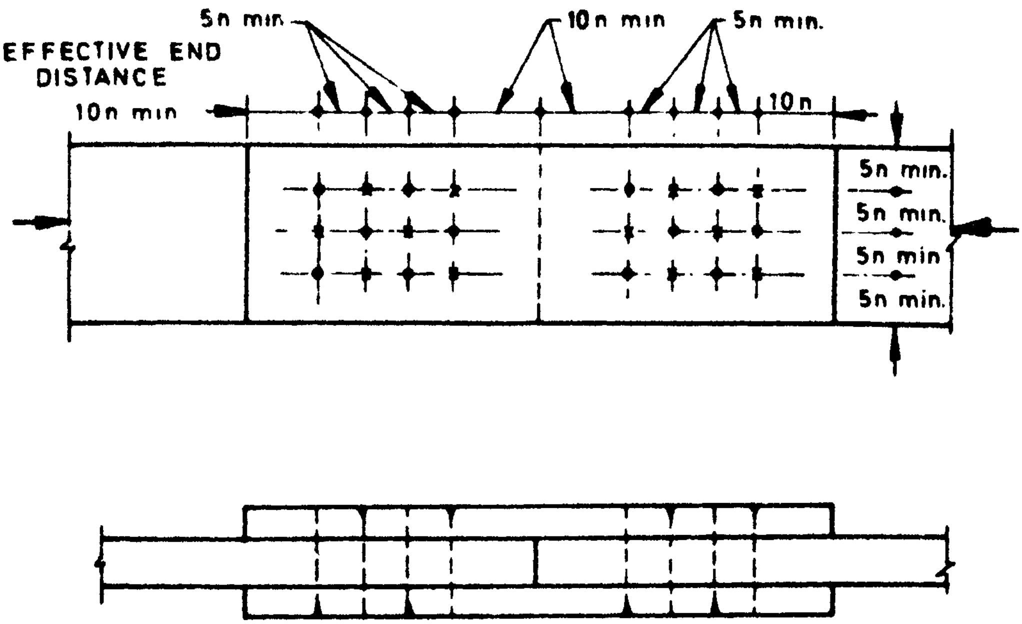
g) All nails should be so arranged that the line of force in a member passes through the centroid of the group of nails, as otherwise suitable allowance should be made for any eccentricity. All projecting nails should be properly clenched or cut to be flush with the face. Adjacent nails should preferably be driven from opposite faces.

h) When nails are driven through a lap joint from the side of the thinner member, the length of penetration of nails in the thicker member should be 1½ times the thickness of the thinner member subject to the maximem thickness of thicker member. For butt joints the nails should be through the entire thickness of the joints. When in doubt preference should be given to more number of vertical rows rather than more nails in a row. When prebore is necessary for the nails, the diameter of pre-bore should be lesser than the diameter of the nail by atleast 0.5, 0.1 and 1.5 mm in very hard or dense woods, medium dense, and soft or light woods respectively.

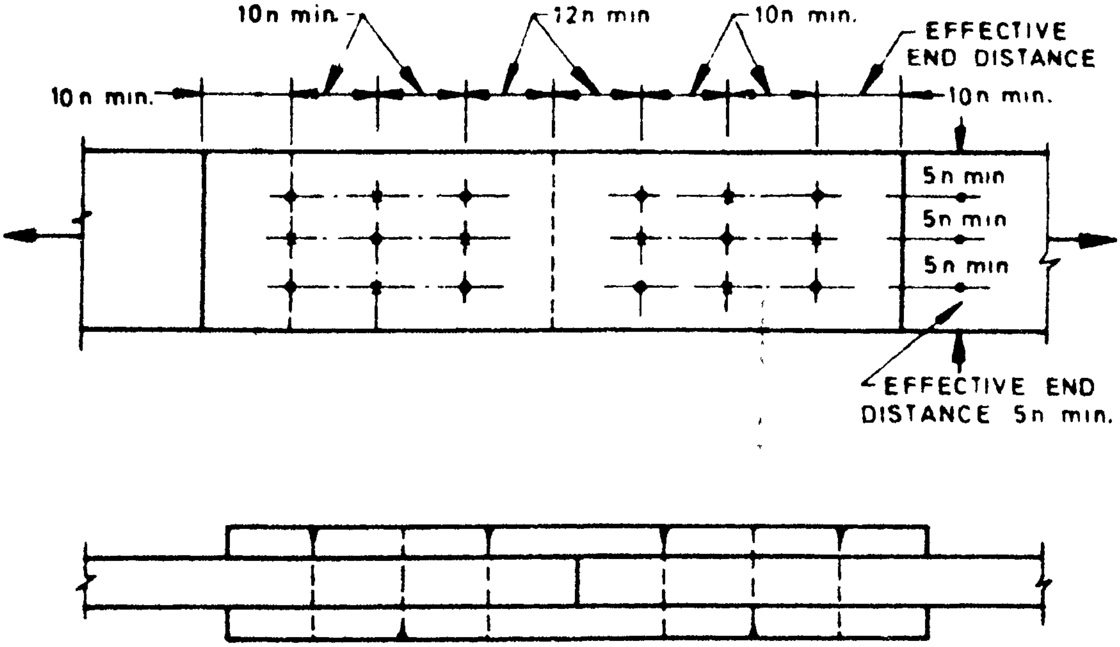
j) Nail jointed structures should be periodically inspected for corrosion, or looseness of nails, joints, etc, and preferably maintained by painting or reinforcing the nailing scheme.

k) See examples 5 and 6 of Appendix K for designing nailing scheme.

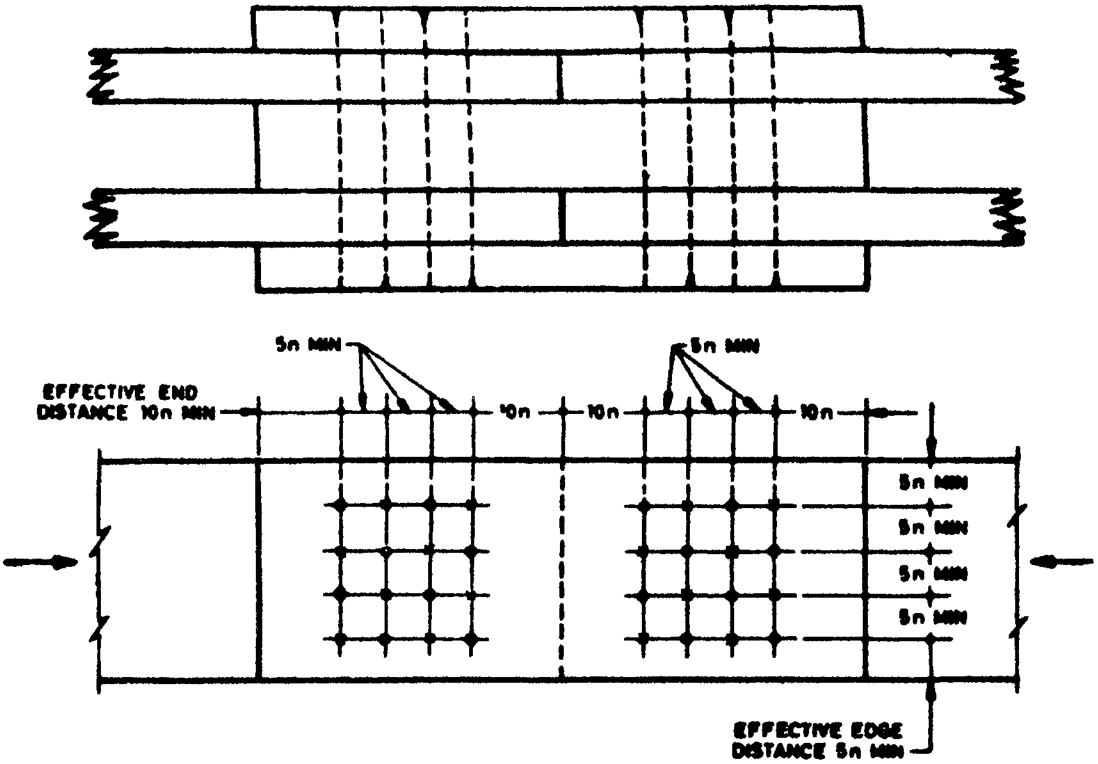
6.2.11.3 Nail jointed designs have also been employed for laminating wood beams mechanically (IS : 4983-1968). The beam is made of 2 to 3 cm thick planks placed vertically with joints staggered in the adjoining planks at a minimum distance of 30 cm and a maximum of 60 cm. They are jointed by minimum number of 4 nails in a vertical row at regular intervals not exceeding 7.5 cm to take up not only horizontal shear forces but also to keep the planks in position. In such laminations lower grade material can be used in the interior where the stresses are lower compared to extremes. In the above



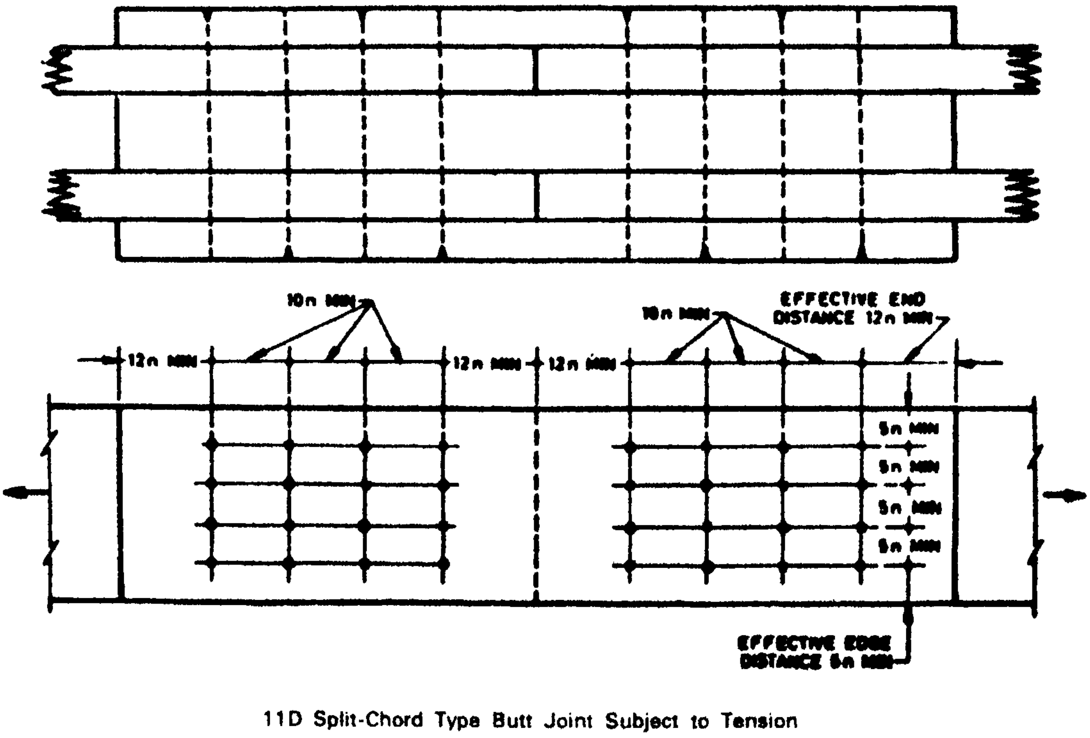
11A Monochord Type Butt Joint Subject to Compression



11B Monochord Type butt Joint Subject to Tension

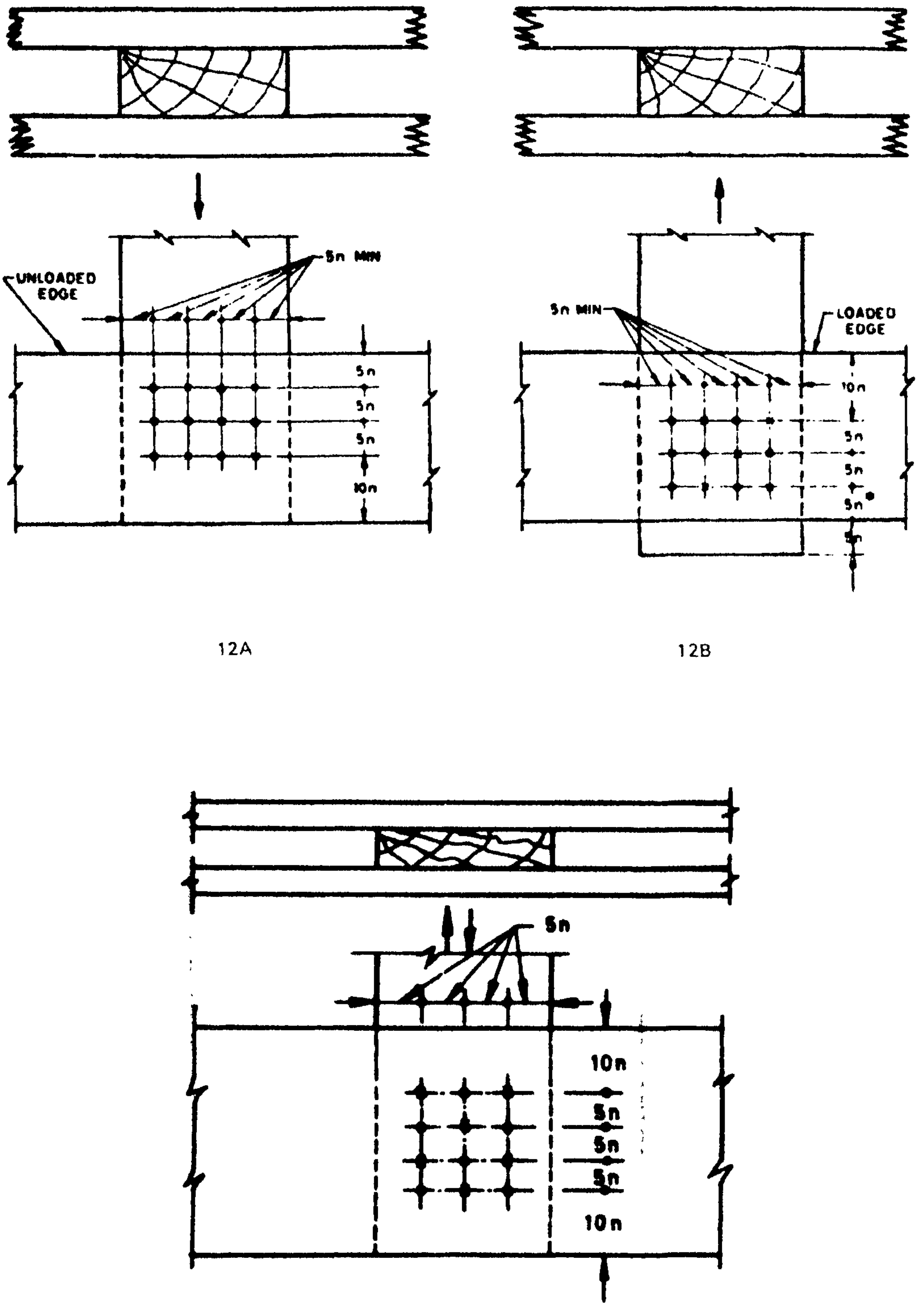

5n MIN
EFFECTIVE END DISTANCE 10n MIN
10n
10n
5n MIN
10n
5n MIN
5n MIN
5n MIN
5n MIN
EFFECTIVE EDGE DISTANCE 5n MIN

11C Split-Chord Type Butt Joint Subject to Compression


10n MIN
12n MIN
12n MIN
12n MIN
10n MIN
EFFECTIVE END DISTANCE 12n MIN
5n MIN
5n MIN
5n MIN
5n MIN
EFFECTIVE EDGE DISTANCE 5n MIN

11D Split-Chord Type Butt Joint Subject to Tension
n = shank diameter of nail

FIG. 11 SPACING OF NAILS IN A LENGTHENING JOINT



12A

12B

12C

*5n may be increased to 10n, if designed width of chord member permits. Otherwise the end of the loaded web member may be extended by at least 5n Min.

n = shank diameter of nail

FIG. 12 SPACING OF NAILS WHERE MEMBERS ARE AT RIGHT ANGLES TO ONE ANOTHER

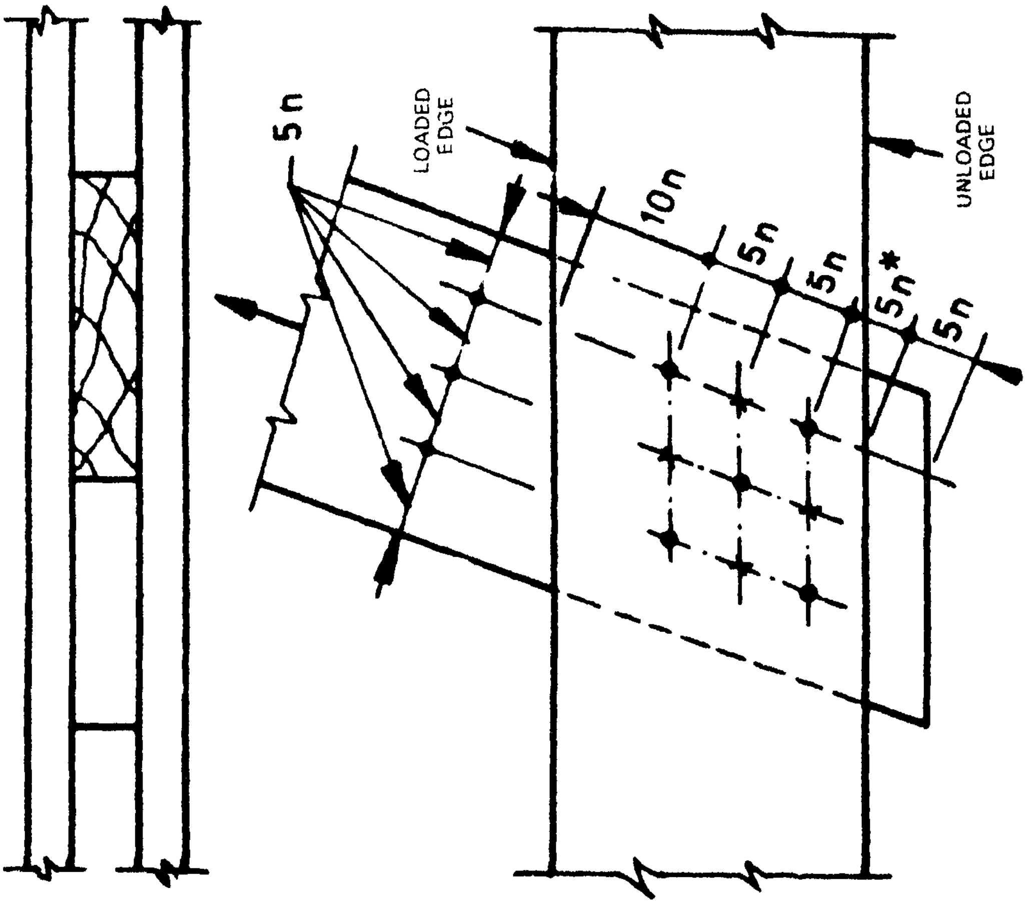


Fig. 13B

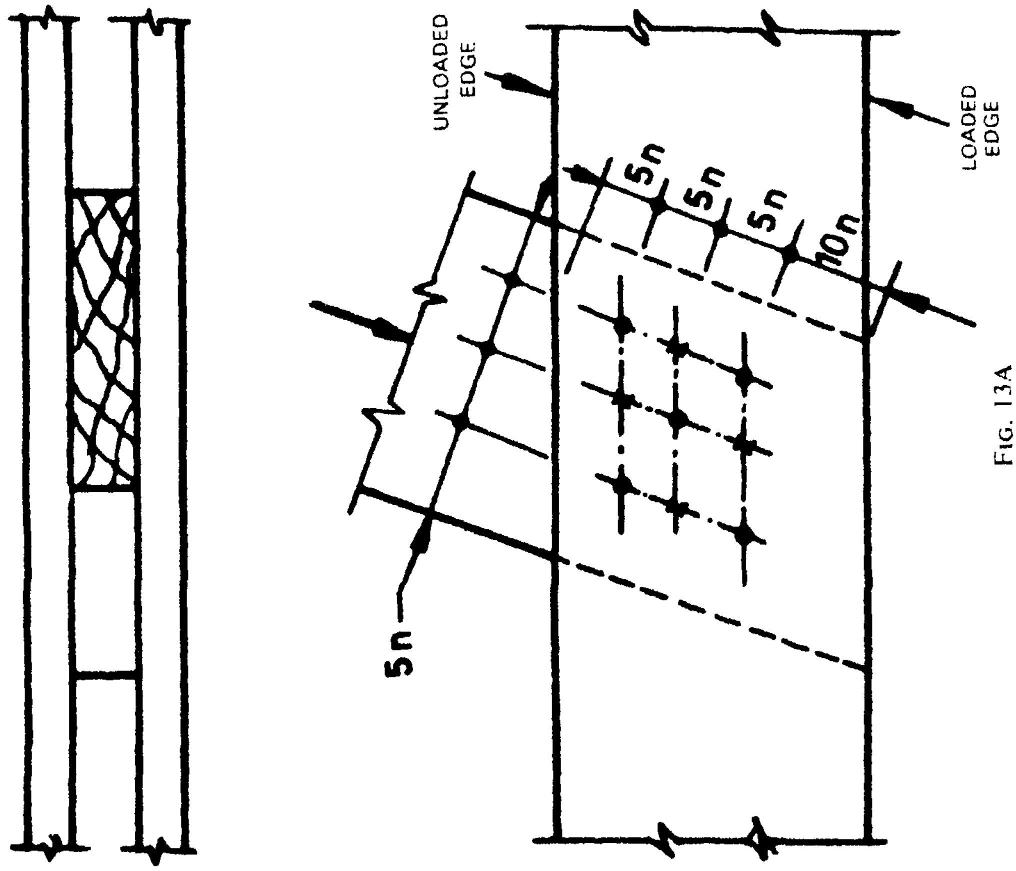
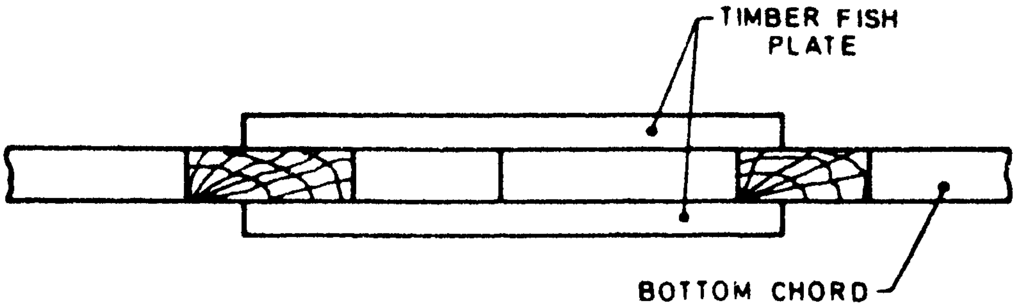


Fig. 13A



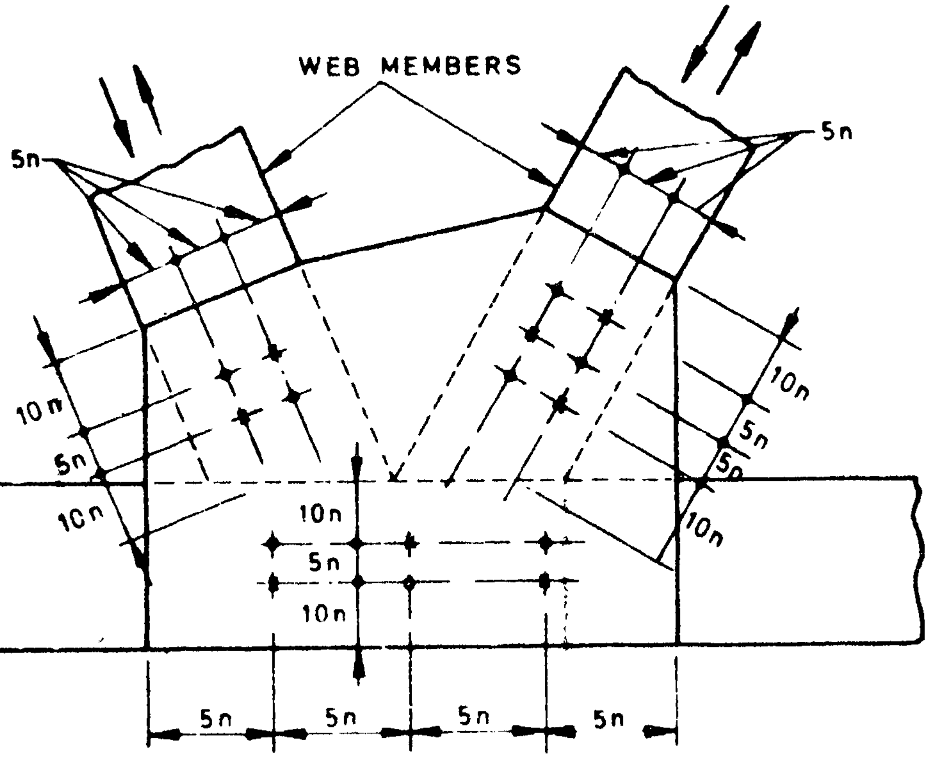


FIG. 13C

*5n may be increased to 10n, if designed width of chord member permits
Otherwise the end of the loaded web member may be extended by 5n, Min
n = shank diameter at nail

FIG. 13 SPACING OF NAILS AT NODE JOINTS WHERE MEMBERS ARE INCLINED TO ONE ANOTHER

referred specification, the maximum depth and length of the planks are recommended to be from 25 to 200 cm respectively. But a minimum depth of the beam for nails 3.75 mm and 4 mm diameter; and 12.5 cm for nails of 5 mm diameter is recommended.

6.2.12 Design of Bolted Construction Joints

6.2.12.1 *General* - For total prefabrication, bolt jointed construction is the most befitting idea for timber structural components. Bolt jointed construction units give better facilities as regards workshop ease, transport convenience and re-assembly at site of work. This technique is best suited for defence purposes for semi-permanent structures (sheds) which are required to be erected at high altitudes and in far off places. Mass production of structural components in factories can thus be made far rational.

6.2.12..2 *Design considerations* — Beams shall be designed in accordance with NBC (Part IV/ Section 6).

Where a number of bolts are used in a joint, the allowable load in withdrawal or lateral resistance shall be the sum of the allowable loads for the individual bolts.

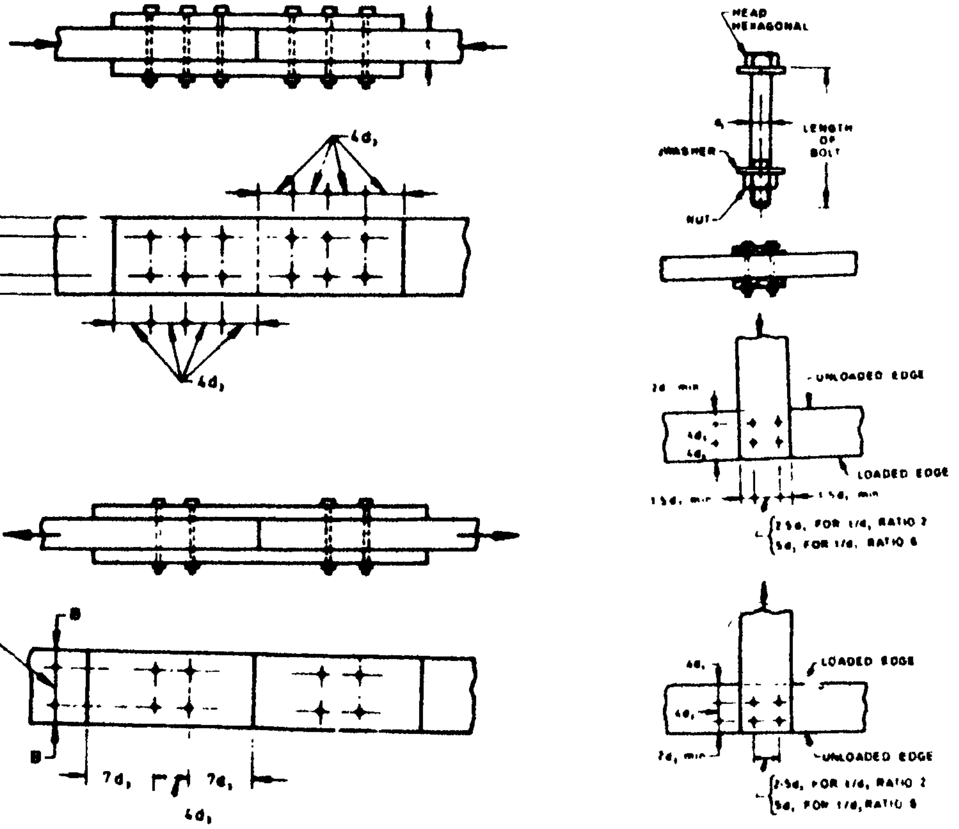
6.2.12.3 *Arrangement of bolts* - The following spacings in bolted joints shall be followed (*see* Fig. 14) :

a) *Spacing of bolts in a row* — For parallel and perpendicular to grain loading = $4d_1$.

b) *Spacing between rows of bolts*

   1) For perpendicular to grain loading = $2.5d_1$ to $5d_1$ ($2.5d_1$ for t/d_1 ratio 2 and $5d_1$ for t/d_1 ratio of 6, where t is the thickness of main member and d_1 is the diameter of the bolt used).

   2) for parallel to grain loading: At least $(N - 4)d_1$ with a minimum of $2.5d_1$, where N is total number of bolts. Also governed by net area at critical section which should be 80 percent of the total area in bearing under all bolts.



14A Spacing of Bolts in Lengthening Joints (Joints loaded parallel to grain)

14B Spacing of Bolts at Node Joints (Joints loaded perpendicular to grain)

$A = (N - 4)\ d_1$ or $2.5\ d_1$ whichever is greater. Also governed by net area at critical section (area should be 80 percent of the total area in bearing under all bolts).
N = total number of bolts in the joint.
B = 1.5 d_1 or half the distance between rows of bolts, whichever is greater.
d_1 = diameter of the bolt.
t = thickness of the main member.

FIG. 14 TYPICAL SPACING OF BOLTS IN STRUCTURAL JOINTS

c) *End distance* — 7 d_3 for soft woods in tension, 5 d_3 for hardwoods in tension and 4 d_3 for all species in compression.

d) *Edge distance*

   1) For parallel to grain loading 1.5 d_3 or half the distance between rows of bolts, whichever is greater.

   2) For perpendicular to grain loading, the loaded edge distance shall be at least 4 d_3.

6.2.12.4 For inclined members, the spacing given above for perpendicular and parallel to grain of wood may be used as a guide and bolts arranged at the joint with respect to loading direction.

6.2.12.5 The bolts shall be arranged in such a manner so as to pass the centre of resistance of bolts through the intersection of the gravity axis of the members.

6.2.12.6 Staggering of bolts shall be avoided as far as possible in case of members loaded parallel to grain of wood. For loads acting perpendicular to grain of wood, staggering is preferable to avoid splitting due to weather effects.

6.2.12.7 *Bolting* — The bolt holes shall be bored or drilled perpendicular to the surface involved. Forcible driving of the bolts shall be avoided which may cause cracking or splitting of members. A bolt hole of 1.0 mm oversize may be used as a guide for pre-boring.

6.2.13 *Anti-termite Construction [IS : 6313 (Parts 1 to 3)-1981].*

6.2.13.1 It is well known that subterranian termites cause considerable damage to timber and other cellulosic materials used in buildings. For understanding classification of termites, development of their colonies and recognizing their presence in buildings, a reference may be made to note in Appendix A of IS : 6313 (Part 1)-1971. However, at sites where the presence of such termites is recognised, special precautions are required to be taken. There are many methods which prevent a termite attack and these are briefly discussed below, and any one or more of these can be adopted depending on the intensity of termite infestation and other local circumstances.

a) Timber used may be such as are resistant to termite attack (that is, heartwood of very durable species).

b) Foundations and sub-base of ground floors should be free from cracks.

c) For protection against termite attack from surrounding areas of a building, a termite metal shield or masonry groove around the periphery of the building may be provided, and a cement concrete apron wall around the building is recommended. It should be remembered that the function of termite shields, masonry grooves, etc, is to cause termites to build their entry tunnels at such places which can be easily detected on periodical inspections, and facilitate further appropriate control measures. Termite shields are made of galvanized sheet of 0.63 mm (conforming to IS : 277-1977), embedding 50 mm in the cement concrete subfloor, with 50 mm horizontal projection on the external side and further projection of 50 mm bent downwards at an angle of 45°. Joints in termite shields should be made by lapping the ends atleast 20 mm lengthwise and soldering the same. Initial cost of installation, frequent maintenance, occasional replacement after installation and also sharp edges of the metal shield projecting out causing injury to children playing nearby in the residential buildings. The metal shields can be conveniently used for grain storage godowns, warehouses, etc. Where timber columns exist, termite caps can be used at the basement.

d) Some pre-constructional chemical treatments can be undertaken [IS : 1003 (Part 2)-1981]. All the termite mounds in the neighbourhood should be broken and water suspensions or emulsions of the following may be poured on the destroyed mounds: (1) 0.5 percent chlordane, (2) 0.5 percent heptachlor, and (3) 0.25 percent aldrin.

e) Treating the soil beneath the building and around the foundation by any one of the following emulsifying concentrates provides sufficient chemical barrier between termites and the wood used in buildings. The chemicals are: (1) aldrin 0.5 percent (IS : 1307-1982), (2) heptachlor 0.5 percent (IS : 6439-1978), and (3) chlordane 1 percent (IS : 2682-1966). Since these chemicals are chlorinated hydrocarbon insecticides, they are poisonous and require careful handling and, where there is any risk of wells or other water supplies becoming contaminated, they should be avoided. The same chemicals can also be used for treatment to older buildings infested with termites after careful examination of the source of infestation. If any wood-work in such building is completely damaged it should be carefully replaced by new timber properly treated, but in cases where no serious damage has already taken place but is likely to cause damage if not attended to, it is recommended that 6 mm diameter holes may be bored in slanting positions in the concerned wood members (like chowkats, joists, purlins, shelves, etc) and the above chemicals may be liberally infused into them.

6.2.14 *Antimagnetic Structures*

6.2.14.1 In some of the harbour constructions, mine sweeping boat constructions and special laboratories, particularly in Navy, sometimes a need arises to construct antimagnetic structures. In such cases bolts, nails, and metal connectors should be avoided. Examples exist of using wood dowel pins, dowel rods or bamboo pins for the joints. Indian Forest Records [Vol. 3, No. 3(1943) by V.D. Limaye] gives details about manufacture of bamboo nails by special tools. It is claimed that bamboo nails of 8 or 9 SWG have the same holding power as MS nails of 12 SWG. In all such cases, it would be preferable to design the joint on the basis of test data obtained with the designed joint. Depending on the locations, whether it is under water, or in open air, and the sizes of jointing members, etc, appropriate adhesives which are not impaired by such exposures may be employed at the joints. Synthetic resin glues are often considered adequate for the purpose.

6.2.15 *Constructions in Chemical Factories*

6.2.15.1 Most of the timbers and metal parts in chemical factories are likely to be attacked by chemical fumes. There are very few timbers such as teak and some conifers which are resistant to acids and alkalies. Acids up to a concentration of 10 percent with conifers and 5 percent with hardwoods, do not very much affect the wood in the cold. It has also been observed that with alkalies wood swells beyond water swollen conditions. Other timbers recommended in Indian Forest Bulletin [No. 119 (1943) by D. Narayanamurthi] for safe use in chemical factories are white siris, pussar, sissoo, white cedar, cypress, dhaman, jarul, lendi, kail, chir, kindal with proper treatments, wherever necessary. As metals used at joints may get attacked and corroded by chemical fumes, they can be avoided and replaced by all wood joints. Hence properly treated timbers so as to neutralize the effects of acids and alkalies, or appropriately coated by commercial paints, some types of resin impregnated and compressed timbers (known as compregs) and such other forms of improved woods, can be tried. So also, joints will have to be appropriately protected. Quite often commercial paints, shellac treatments, asphalted paraffin, etc, seem to have served the minimum purpose, but more scientific data will be needed for drawing up proper specifications of treatment. In all such cases, it is always recommended that accelerated tests may be performed on treated material and joints before design or fabrication work is undertaken. If such treatments do not affect the structure of the fibres of wood, strength is not seriously affected. However, it would be advisable to undertake the strength tests of the material also before and after the accelerated exposure conditions.

6.2.16 *Marine Constructions*

6.2.16.1 Very few timbers remain stable under marine conditions, and so several treatments have been tried recently to protect timber exposed to marine conditions. The type of marine organisms existing in different harbours of India are not exactly the same. In some parts like Cochin and Bombay there are mainly marine baorers which destroy the wood and in some parts like Visakhapatnam there is a predominance of marine fowlers which only settle down on wood surfaces, without destroying the material but adding considerably to its weight. Sometimes along with the new incoming ships into Indian harbours new types of marine organisms may come. So far the treatments recommended in IS : 401-1982 for marine purposes are considered adequate enough. In some cases treatments with fish oils have been found useful. However, in view of the possible changes in the marine conditions as mentioned above, the treatments recommended so far, may not always be adequate and consequently continuous observations, testing and evaluation are required at important areas. Hence in the design of timber constructions for use under marine condition, a thorough knowledge is required of the existing and possible organisms which may affect the timbers and the treatment given to them. Study should also be made of tidal conditions and their effect on the material used. A proper design can be undertaken only when all the information is available. In view of not many satisfactory results so far, in the recent years trends have been in the direction of avoiding timber and timber products for such constructions and replacing by concrete for jetties, etc, and vulcanized rubber where cushioning effects are required. However R & D activities are still going on for developing and improving wood and wood products for marine constructions wherever they are still considered useful and economical keeping in view particularly the need of changing the jetty designs fairly frequently in some of the small harbours.

6.2.17 *Timber Doors, Windows and Ventilators*

6.2.17.1 In the design of timber doors, etc, there are no specific aspects of strength, except that the sizes should fit in with rationalized metric system, and the species should have a good dimensional stability, and the finished doors should stand the type tests according to IS : 4020-1967. Another important consideration has been the use of proper adhesive for the manufacture of the doors to withstand delamination of glued parts due to varying humidity and temperatures they are subjected in actual conditions and simultated tests. The acceptance tests and guidance for selection of material are covered in a number of Indian standards. Those include timber panelled and glazed door shutters [IS : 1003 (Part 1)-1977, IS : 1003 (Part 2)-1966], timber door.

window and ventilator frames (IS : 4021-1976). Standards have also been formulated on cellular and hollow core type flush doors with facings of plywood, particle boards, and hardboards [IS : 2191 (Parts 1 and 2)-1980]. Although in the earlier versions exterior and interior type grades were permitted. In view of certain malpractices in the trade, only one grade of flush doors, bonded with phenol formaldehyde (BWP) are now recommended in the standards.

6.2.18 *Poles, Posts, Pitprops and Piles*

6.2.18.1 Poles, posts and pitprops of solid wood are primarily decided on the basis of such species which are available in round form and are of sufficient strength. A number of wood poles are already in use for electric distribution system in several states of India. If the species are not naturally durable, they require to be treated in accordance with **4.4**. The Indian standard for wood poles for overhead power and telecommunication lines is covered in IS : 876-1970 which divides the species available in the pole form, into three main groups A, B and C according to their modulus of rupture taking sal, teak and chir as general reference species. Accordingly in Group A, there are six species for which the modulus of rupture is more than 850 kg/cm², in Group B there are 22 species for which the modulus of rupture lies between 630 and 850 kg/cm². In Group C there are ten species for which the modulus of rupture lies between 450 and 630 kg/cm². In each group seven different load classifications as given below are recognized and the length of the poles and the girth dimensions at ground line and also the girth at the top of the pole are given. The seven load classifications followed in India are given below:

a) Ultimate breaking load not less than 1 350 kg,

b) Ultimate breaking load between 1 100 and 1 350 kg,

c) Ultimate breaking load between 850 and 1 100 kg,

d) Ultimate breaking load between 700 and 850 kg,

e) Ultimate breaking load between 550 and 700 kg,

f) Ultimate breaking load between 400 and 550 kg, and

g) Ultimate breaking load between 300 and 400 kg.

The circumferences at the ground line for three groups of species, for the two extreme heights and the two extreme load classifications are given in Table 25 for guidance. For other cases reference may be made to IS : 5978-1970 or IS : 876-1970.

TABLE 25

LOAD CLASSIFICATION	HEIGHT OF THE POLE ALONG GROUND LEVEL (m)	CIRCUMFERENCE AT THE GROUND LINE FOR DIFFERENT GROUPS (cm)		
		A	B	C
1	12	83	87	96
	4.8	60	63	70
7	12	54	57	63
	4.8	40	41	45

These figures have been worked out on the basis of design of wood poles according to IS : 5978-1970 in which the pole has been considered as a verticle cantilever fixed firmly in the ground; the effect of wires have been considered, and a factor of safety of 3.5 has been assumed, keeping in view that the lowest factor of safety permitted in the specification is 2.5 or that which is permitted by the statutory rules of each state in India, based on *Indian Electricity Act*. The factor of safety is given by:

$$\frac{\pi D_g^3}{32} \times \frac{R}{100} \times \frac{1}{M}$$

where

D_g = diameter of the pole at ground line in cm,

R = modulus of rupture of the species,

$M = M_p + \Sigma M_{cn}$,

$M_p = \frac{PH^2}{900}(D_g + 2D_t)$
= overturning moment due to wind load on the pole in kg. m,

$M_{cn} = (M_{c1}, M_{c2}, \text{etc}) = P_c L_n \left(\frac{S_1 + S_2}{2}\right)$
= overturning moment due to wind pressure on the nth wire,

D_t = diameter of the pole at the top in cm,

H = height of the pole above the ground line in metres,

L_n = height of the nth conductor in metres,

S_1 and S_2 = lengths of spans on each side of the pole in metres,

P_c = wind pressure on each conductor in kg per metre run, and

P = design wind pressure for the region.

Where stays are used, crippling load due to vertical components of the forces in the stays is calculated using the following formula:

$$\text{Crippling load in kg} = \frac{4.16\, D_e^4}{L_e^2}$$

where

D_e = effective diameter of the pole in cm,

$$= (D_t) + \frac{L_t - L_g + 0.9}{0.9\,(L_t - 1.8)} \times \left[\begin{pmatrix}\text{diameter at 1.8} \\ \text{metres from butt} \\ \text{in cm}\end{pmatrix} - D_t\right]$$

L_t = full length of the pole,

L_g = length of the pole in the ground, and

L_e = effective length of the pole between the top and 0.3 metres below the ground line in metres $= L_t - L_g + 0.3$.

6.2.18.2 Where long lengths of wood poles would not be available, simple designs of jointed poles of round wood have been described in IS : 7610 (Part 3)-1975. Some of the various methods of joining and the loss in the joint strengths have been described in the specification. The general principles of grouping the species and selecting load classifications are the same as explained above. The specification also prescribes the general requirements, the permissible and avoidable defects, and care required in the preparation of the components. The easiest and cheapest type of jointed pole recommended and used in most of the places is the wire-bound lap-jointed pole which is obtained by winding two bands of galvanized wire of 8 SWG around the half-lap made in each of the pole sections. The minimum number of required turns (N) in each of the band in the wire-bound lap jointed pole is given by:

$$N = \frac{p.y}{k.d}$$

where

N = number of turns required at each band,

p = anticipated load + 30 percent cover safety,

y = distance from load point to the farthest point of the lap,

k = 1.8 t (where t = breaking load of the wire), and

d = distance between central line of nearest band and the farthest point of the lap.

The other types of useful joints recommended with appropriate criteria of sizes and shapes of hardware used are:

a) V-type lap jointed poles using flat bars or angle iron with bolts,

b) Z-type lap jointed poles using flat bars or angle iron with bolts,

c) angle iron used vertically with bolts on butt jointed poles,

d) half-sleeve half-lap jointed poles, and

e) half-sleeve tongue and groove jointed poles.

6.2.18.3 After designing and erecting wood poles there is a need of continuous care and maintenance of these poles as in the case of any other kind of poles particularly at the ground line portion. As the wood poles are continuously subjected to drying and wetting there is a danger of possible decay and quick deterioration at these portions. IS : 6711-1972 covers not only some erection precautions, some periodic maintenance and observation procedures, preparation of reports and remedial measures against biological and mechanical damages, but also methods of replacements of poles when they are beyond remedial measures. IS : 2203-1976 prescribes the species and permissible defects for wooden cross-arms for use with the above wood poles. It also deals with testing of suitability of different species and standard sizes for wooden cross-arms.

6.2.18.4 Although wood poles can be designed and suitable species can be selected on the basis of their basic strength, their dimensions and other criteria prescribed in IS : 7610 (Part 3)-1975, there would still arise occasions to test the full poles for their behaviour under actual loads. This would not only give the strength data of the full or the jointed poles to compare with the design loads by taking into consideration the cumulative effects of all permissible defects but such data will also ensure the adequacy of factors of safety employed in pole design. IS : 1900-1974 prescribes how the poles are tested in a fixed or movable crib as a cantilever taking movement of the load point (at a distance of 60 cm from the top of the pole) in the direction of the applied load, as well as in the direction of the length of the pole. It also prescribes a method of testing poles on a universal high capacity testing machine. After testing the pole in full length small clear specimens are taken out from the unstrained portions of the butt ends to find the basic strength of the material and compare the same with the observed maximum load for failure of the pole. The poles are generally tested in: (a) green condition, (b) air-dry condition, (c) treated condition, and (d) sometimes in air-seasoned and butt-soaked condition. In the recommended methods of tests, there are 'major' tests on full sized poles and 'minor' tests on small clear specimens according to IS : 1708-1969 on atleast one sample for each test taken from the least stressed (that is, butt portions) of each pole. The major tests consist of:

a) weight of the full pole, and

b) bending (as a cantilever in the crib method and as a beam on supports in the machine method with the load applied on the ground line).

In the cantilever method the maximum fibre stress (f) is given by

$$f = \frac{P.l}{Z}$$

where

P = load at failure in kg,

l = distance between load point and the point of break,

Z = $C^3/32\ \pi^2$, and

C = circumference at the point of break which may be either at the ground line or at a place where the diameter is equal to 1.5 times the diameter at the point of occurrance of the resultant load—which is usually the load point at a distance of 60 cm from the top of the pole.

The modulus of elasticity in the cantilever method is given by:

$$E = \frac{PL^3 D_g}{3 I_g\, d\, D_l}$$

where

P = applied load at the top,

L = corrected lever arm of the cantilever,

D_g = diameter of pole at the ground line,

I_g = moment of inertia at ground line,

d = deflection of load point in cm, and

D_l = diameter of pole at load point.

In the machine method the maximum fibre stress (f) at the ground line is calculated by:

$$f = \frac{(T + t - W/2)a}{0.098\,2 \times D_l^3}$$

where

T = tip reaction at maximum load due to super-imposed load in kg = $p.b./L$,

t = tip reaction due to the dead weight of the pole,

p = maximum superimposed load on the pole in kg,

b = distance from load point to butt support in cm,

L = distance between the tip and butt support,

D_l = diameter of the pole at load point in cm,

a = distance from load point to top support, and

W = weight of the section of the pole from the load point to the tip end in kg.

Similarly, the modulus of elasticity, E, is calculated by the formula:

$$E = \left[\frac{4a^3 b}{3}\right] \left[\frac{T}{\Delta\ A^2 B\,(AL - Bb)}\right]$$

where

E = modulus of elasticity in kg./cm^2,

a = distance from ground line to tip support,

b = distance from ground line to butt support,

Δ = observed deflection at ground line measured from initial horizontal neutral axis,

T = tip reaction from superimposed load in kg,

A = radius of the pole at ground line in cm,

B = radius of the pole at tip support in cm, and

L = length between points of support ($a + b$) in cm.

Where a superimposed load is measured at ground line the tip reaction, T, can be calculated from the formula:

$$T = \frac{p\,b}{L}$$

In the minor tests from unstressed or least stressed portions of the pole (that is, butt) the following tests only are done according to IS : 1708-1969 on small clear specimens.

a) Moisture content,

b) Specific gravity,

c) Static bending,

d) Compression parallel to grain, and

e) Shear

At least one clear specimen from each pole is taken for each test from each pole.

6.2.18.5 Where solid round wood poles are not available nail jointed timber poles can be made from small dimensioned timber planks for overhead electric distribution lines for low voltages. In this connection IS : 7683-1975 permits sawn timber according to IS : 1331-1971 with defects permitted according to IS : 3629-1966. However, the minimum thickness of planks is recommended to be not less than 45 mm. The nails, as usual in all nail-jointed constructions, should conform to IS : 723-1972. In designing, fabricating and erecting timber posts according to IS : 7683-1975, the following aspects are required to be considered.

a) For overhead electric distribution at straight line locations, the post is subjected to static bending caused by: (1) with load on the surface of the post above the ground, (2) wind load on the conductors and ground wires acting on the horizontal span, and (3) unbalanced pull in the longitudinal direction due to breakage of wires. At angle locations, particularly when guy rope stay is fixed, it is also subjected to a vertical downward load. For these reasons the posts are appropriately designed in bending (as cantilever) and as a column in accordance with IS : 883-1970. The wind pressure on posts and wires are to be in accordance with IS : 802 (Part 1)-1977.

b) The joints are also to be designed for loads as above and shall conform to IS : 4983-1968. The number of joints should be as less as possible and some type designs for a maximum height of 8.25 m above the ground level are available at the Forest Research Institute.

c) The nail jointed timber posts, after having been fabricated according to practices recommended in IS : 7683-1975 and adopting nailing procedures recommended in IS : 2366-1963, are erected well above ground level, raised over cement concrete dwarf pillar and fixed by means of MS channels, bolts, or they are buried in ground, and encased with cement concrete foundation. The design and construction of foundation for timber posts may be in accordance with the provisions laid down in IS : 4091-1979. Necessary anti-termite measures may also be carried out according to IS : 6313 (Part 2)-1981.

d) In the process of fabrication of nail jointed timber posts, IS : 7683-1975 permits a deviation of either 15 mm at the top in either direction, or 15 mm at centre in either direction measured from the straight line joining the end points of the post. Besides, the specification also prescribes clauses for marking, stacking of posts before use and the various stages and precautions to be taken in the erection of the posts. The prescribed painting and maintenance clauses are also generally in accordance with 9. Finally, one GI sheet cap is recommended to be fitted at the top of the post for prevention of any rain water entering through the ends of the jointed pieces.

e) Generally speaking, both coniferous and non-coniferous structural timbers are considered suitable for making of nail jointed timber posts, but owing to the fact that these posts are likely to be exposed to extreme vagaries of weather, careful choice of species with high durability, strength, and retention of shape are recommended in IS : 7683-1975. Based on these considerations and backed by proof tests on prototype designs with various species, three choices of preferences are recommended as follows: (1) the first is based on naturally durable species with high durability of heart wood, (2) the second on moderately or non-durable species but satisfactorily treatable heart wood, and (3) the third choice with moderately durable and not easily treatable species, and so pressure processes are required to be employed. Where sapwood is present it, no doubt, requires complete treatment and protection.

6.2.18.6 Design testing and recommended species for pitprops are covered in IS : 6346-1971. Chiefly, they are based on long usage and experience and contain a high degree of factor of safety as the conditions in mines are very unpredictable. They vary very much in humidity and temperature and the prop should be capable of taking compressive and bending loads suddenly coming on them. Their erection and fixing are also such that they can be easily altered or replaced from time to time. Specification for use of timber in coal mines is covered by IS : 4424-1967 in which 20 species like babul, kokko, benteak, bijasal and kindal have been recommended. Round pitprops are usually 10 to 12 cm in diameter and lengths vary from 100 to 500 cm. Rectangular bars vary in breadth from 5 to 10 cm, width from 10 to 25 cm and lengths from 100 to 400 cm. In the recommended methods of tests for timber pitprops for mines the major tests comprise the following:

a) compression parallel to grain from which the compression strength is calculated by SP/A, where S is the strength, P is the load and A is the cross-section;

b) moisture distribution through the prop;

c) weight of the prop;

d) eccentricity of the prop which is defined as the percentage ratio of the deviation between neutral axis and the longitudinal axis to the length of the prop, that is,

$$e = \frac{d \times 100}{L}; \text{ and}$$

e) length/diameter (L/D) ratio of the prop.

From the clear specimens selected from props, the minor tests are done according to IS : 1708-1969, on atleast 3 specimens for each test from each prop. The minor tests are: (a) compression parallel to grain, (b) static bending, and (c) moisture content. The data on major and minor tests help to decide the suitability of the species and the safe dimensions, and the moisture content required for the purposes. The above specifications do not indicate the minimum of properties required.

6.2.18.7 Timber piles are covered in IS : 2911 (Part 2)-1980. Depending on the use and size of piles they are classified as Class A and Class B. For Class A, intended for heavy bridges, docks, and wharves, the butt diameter is recommended to be not less than 30 cm. For Class B, which are generally used for temporary works and also used for compaction of ground, are not to be less than 10 cm in diameter. The wood species recommended are same as given in IS : 883-1970 and now covered in Appendices G and H. The general requirements are:

a) lengths less than 12 m have a tolerance of ± 30 cm, and lengths 12 m and more have a tolerance ± 60 cm;

b) circumferences (measured under bark) may be less by 5 cm only in 10 percent of the piles. This condition relates only to bulk purchase rather than design;

c) ratio of heartwood diameter to the total butt diameter of the pile should not be less than 0.8. This is a condition to safeguard consequential deterioration of sapwood; and

d) both ends should be sawn at right angles to the length. This is a condition to ensure the load axis to be well within the pile material and nearest to the pile axis only.

The choice of the pile is governed by water table condition and other aspects of the site. The bearing capacity and spacing of piles is considered same as for RC piles covered in IS : 2911 (Part 1)-1979. When test data on load bearing capacity is not available the load carried by the pile is determined by the following formulae :

For piles driven by drop hammer:

$$P = \frac{16\,WH}{S + 2.5}$$

For piles driven by single acting steam hammer:

$$P = \frac{16\,WH}{S + 0.25}$$

where

P = safe load on pile in kg,

W = weight of monkey in kg,

H = free fall of monkey in m, and

S = penetration of pile in cm to be taken as average of three blows.

In IS : 2911 (Part 1)-1979, it has been permitted that the normal working stress may be exceeded by not more than 100 percent during driving because of impacts. Proper precautions are also suggested for handling of timber piles so as not to bruise or damage the wood, and necessary instructions have been provided in the specification for driving, selection of pile hammer, control of alignment and replacement of defective piles. It has been mentioned in the specification that foundation piles, when cut off below the ground water level, apparently have an infinite life. However, when the conditions are not favourable, they should be given suitable treatments. The following factors have been considered important for record of data in timber piles:

a) dimension of pile;

b) depth driven;

c) sequence of driving,

d) final set for the last ten blows or as may be specified,

e) type and size of hammer and its stroke, or with double acting hammers, the number of blows per minute, and

f) type and condition of the packing on the pile head and the dolly in the helmet.

6.3 Timber Fasteners

6.3.1 *General* From the above discussions on trusses and special constructions it has been amply brought out that in all timber constructions, the joints are the most important and require very careful consideration. Examination of some old timber structures and analysis of causes of their failures or their becoming unserviceable after some time have confirmed the fact that more than ordinary attention is required at the design of the joints. Failures at joints could be either due to insequency of design itself not being based on well founded theories, test data, or also due to bad fabrication and fitting which develop unaccounted stresses and consequent slips. It has also been observed in some cases that bad erection and maintenance has also been responsible for failure of joints due to undue mechanical damages and consequent decay of the material if not properly protected. Differential moisture content and consequent differential shrinkage and swelling between the different components at the joint, can also be another reason of failures at the joint. Under these experiences, it is obvious that the design engineer must develop the overall concepts of all stages of timber construction right from the material stage to the actual end use in practice. Several R & D efforts have been made in the direction of developing suitable fasteners for most economical and efficient joints for different types of constructions to study the effects of variables on such joints, and to derive the allowable stresses for the different types of fasteners. Some of the attempts made in India are given below and brief mention has also been made to explain the practices in other countries.

6.2.3 *Nails, Spikes and Screws*

6.3.2.1 These are the most commonly used fasteners from times immemorial for jointing one member of the structure with another. However collection of scientific data and comparative studies on these have been only of recent origin and the conclusions drawn from various sources are summarized below.

6.3.2.2 One of the earliest attempts in India to obtain withdrawal resistance of nails and screws was published by Forest Research Institute, Dehra Dun [Indian Forest Records

(TM) Vol. 1 No. 5 (1956) Nail and screw holding power of Indian timbers]. Systematic test in withdrawal of nails and screws from wood were conducted on several samples from several trees of different species grown in different localities and the results were published under four conditions of testing as below. The values were obtained for withdrawal from side grain as well as end grain:

a) Nails or screws driven in green condition and pulled out immediately,

b) Nails or screws driven in green condition and pulled out after the material has dried to about 12 percent moisture content,

c) Nails or screws driven in the dry material at about 12 percent moisture content and pulled out immediately, and

d) Nails or screws driven in the dry material at about 12 percent moisture content and pulled out after a lapse of about 4 months.

However, only one type of nail of 5 cm length × 12 SWG diamond pointed at the end, and only one type of screw of 5 cm length × 8 SWG have been used as standard for comparison of holding power or withdrawal resistance of different species. Grouping the values of the above as discussed in **3.1.4** by giving suitable weightage factors and adjusting factors, data on 'composite holding power' of various species have been published [*see* SI No. 40, Appendix B), for making a ready comparison of different species in terms of quantitative indices. Analyzing the data under condition (a), it has been inferred that nail and screw holding power roughly follows the following equations:

$H_A = 308\ \rho^{1.65}$ for side grains and $= 246\ \rho^{1.85}$ for end grain
or $H^1_A = 705\ \rho^{1.45}$ for side grain and $= 440\ \rho^{1.65}$ for end grain

where

H = nail holding power (or nail withdrawal resistance) in kg,

H^1 = screw holding power (or screw withdrawal resistance) in kg, and

ρ = standard specific gravity (weight oven-dry and volume green).

In the condition (c), the above values are increased by 1.2 times for nails and 1.5 times for screws. It has been further observed that as drying takes place after nailing, the strength generally reduces. It may be noted that the above values are obtained only for one diameter of nails or screws. It has been established in USA that the withdrawal resistance of nails (including spikes) driven on side grain is given by

$$P = K\ \rho^n d$$

where

P = ultimate load per unit length of penetration,

K = constant depending upon the species and units chosen (separate values for nails and screws),

d = diameter of nail or spike as the case may be,

ρ = specific gravity of the species, and

n = power constant of specific gravity equal to 2.5 for nails (including spikes) and 2 for screws.

This equation shows that the withdrawal resistance for unit length of penetration is proportional to the diameter and so can be suitably extrapolated as desired.

6.3.2.3 In the actual timber constructions the lateral resistance of nails and screws, sometime referred to as shear values, are more important. In foreign literature the values for specific species, or for groups of species are given and these values generally take the form of

$$p = \mathrm{kd}^{\mathrm{n}}$$

where

p = lateral withdrawal load,

k = constant of timber (separate for nails and separate for screws), and

n = 1.5 for nails (including spikes) and 2 for screws.

However, in India a series of tests on different species have been conducted and the standard data of permissible lateral strength published in IS : 2366-1983 and IS : 4983-1968, and reproduced in Table 26 and 27.

6.3.3 *Bolts*

6.3.3.1 *General* — For medium and large spans, such as those required for big sheds, storage areas, industrial trusses, bolt jointing techniques are more useful than nailed jointed members because ease of working in shops, ease of transport, and ease of reassembly and erection at the site. Usually the bolts are of steel rods with either square or hexogonal heads on one side, and threaded portion on the other side to take a threaded nut on the same. Washers are used wherever necessary and particularly when no plates are used. The thickness of nut is usually equal to the diameter of the bolt. As bolt holes are primarily necessary before inserting the bolts it is natural that such bolt hole diameters should be about 1 mm oversize and any forcible driving of the bolt may cause undue splitting or even introduce unaccountable stress concentrations at the tight points.

TABLE 26 PERMISSIBLE LATERAL STRENGTHS (IN DOUBLE SHEAR) 3.55 mm DIA 80 mm LONG IN TIMBER

Sl No.	Species of Wood		For Permanent Construction Strength per Nail		For Temporary Construction Strength per Nail
	Botanical Name	Trade Name	Lengthening joints	Node Joints	(For Both Lengthening and Node joints)
			kg	kg	kg
*1.	*Abies pindrow*	Fir	80	20	120
2.	*Adacia arabica*	Babul	150	110	340
3.	*Albizzia lebbek*	Kokko	200	70	240
4.	*Albizzia odoratissima*	Kala siris	140	50	220
5.	*Anogeissus latifolia*	Axle wood	200	100	290
*6.	*Calophyllum tomentosum*	Poon	160	90	210
*7.	*Cedrela toona*	Toon	150	100	180
*8.	*Cedrela* sp.	gendhalipoma	100	80	210
*9.	*Cedrus deodara*	deodar	90	40	150
10.	*Chukrasia tabularis*	chickrassy	240	80	270
*11.	*Cinnamomum* sp.	Camphor (cinnammon)	120	90	130
12.	*Cupressus torulosa*	Cypress	60	50	180
13.	*Dipterocarpus macrocarpus*	Hollong	170	70	200
14.	*Dipterocarpus* sp.	Gurjan	190	90	190
15.	*Eucalyptus eugeniodes*	Eucalyptus	170	100	300
*16.	*Grewia tiliacfolia*	Dhaman	130	50	240
17.	*Lagerstroemia parviflora*	Lendi	190	50	260
*18.	*Mangifera indica*	Mango	110	90	160
19.	*Mesua ferrea*	mesua	260	80	410
*20.	*Michelia* sp.	champ	130	90	200
21.	*Ougeinia dalbergioides*	sandan	170	110	180
*22.	*Phoebe* sp.	Bonsum	120	60	130
*23.	*Pinus roxburghii*	Chir	110	100	160
*24.	*Pinus wallichiana*	Kail	70	30	90
25.	*Pterocarpus dalbergioides*	Padauk	190	140	230
26.	*Pterocarpus marsupiun*	Bijasal	150	120	270
27.	*Quercus* sp.	Oak	110	110	270
28.	*Schleichera trijuga*	Kusum	230	160	400
29.	*Shorea robusta*	Sal	100	50	190
30.	*Syzygium* sp.	Jamun	150	120	250
31.	*Tectona grandis*	Teak	140	80	130
32.	*Terminalia bellirica*	Bahera	100	100	140
33.	*Terminalia bialata*	White chuglam	180	90	210
*34.	*Terminalia manii*	Black chuglam	230	100	330
35.	*Terminalia myriocarpa*	Hollock	130	100	190
36.	*Terminalia tomentosa*	Sain	160	160	290
37.	*Xylia xylocarpa*	Irul	230	60	330

NOTE — Nails of 3.55 mm diameter are mostly used. The above values can also be used in 4 mm diameter, 100 mm long nails.

*Species requires no pre-boring for nail penetration.

6.3.3.2 *Permissible stresses in bolted joints* — Several experiments indicated that there is some relationships between the average bearing stress limit of the joint, and the ratio of length of the bolt to its diameter in the main member of the joint. For this reason, different countries have published for the species of wood available in their respective countries the basic stresses, parallel and perpendicular-to-grain and proposed modification factors for different L/d ratios of the bolts. These stresses should not be confused with the working stresses of structural timbers but they are to be used only with reference to design of bolted joints only. In India, the engineers have been invariably using the compressive stress on the projected area of the bolt on the timber (approximately length × diameter) either in perpendicular direction or in the parallel direction as the case my be and applying a percentage reduction for different L/d ratios given in Table 28. Further, from some of the results on bolted joints in perpendicular direction it has been observed that in many cases the stress at proportional limit is even more than 100 percent the fibre stress at elastic limit obtained by standard test on specimens of clear wood, and it also depends on the diameter of the bolt. Table 29 gives modification factor for different diameters

TABLE 27 SHEAR STRENGTH VALUE OF NAILS FOR DESIGN OF NAIL LAMINATED BEAMS

Sl No.	Species		Strength per Nail in kg	
	Trade Names	Botanical Names	3.75 and 4 mm dia nails, 75 and 100 mm Long	5 mm dia nails, 125 and 150 mm Long
(1)	(2)	(3)	(4)	(5)
1	Aamari	*Amoora Wallichii*	190	275
2	Axle wood (bakli)	*Anogeissus latifolia*	200	290
3.	Babul	*Acacia arabica*	155	255
4.	Bahera	*Terminalia bellirica*	100	145
5	Bijasal	*Pterocarpus marsupium*	150	220
6.	Birch	*Betula* sp.	130	190
*7.	Black chuglam	*Terminalia manii*	225	325
8	Black siris	*Albizzia odoratissima*	140	205
*9	Bonsum	*Phoebe* sp.	120	175
*10	Champ	*Michelia* sp.	130	190
*11.	Camphor (Cinnamon)	*Cinnamonum* sp.	120	175
12.	Chickrassy (Andaman)	*Chukrasia tabularis*	245	355
13.	Chilauni	*Schima wallichii*	175	255
*14.	Chir	*Pinus roxburghii*	110	160
15.	Cypress	*Cupressus torulosa*	60	90
*16.	Deodar	*Cedrus deodara*	140	205
*17.	Dhaman (MP)	*Grewia tiliaefolia*	280	405
18.	Dhaman (UP)	*Grewia vestita*	130	190
19.	Eucalyptus	*Eucalyptus ewgenioides*	165	240
20.	Fir	*Abies pindrow*	80	115
21.	Gamari	*Gmelina arborea*	80	115
*22.	Gendhalipoma (Assam)	*Gedrela* sp.	110	160
23	Gurjan (Andaman)	*Diptrocarpus* sp.	185	270
24.	Hollock	*Terminalia myriocarpa*	130	190
25.	Hollong	*Dipterocarpus macrocarpus*	170	250
26.	Irul	*Xylia xylocarpa*	235	340
27	Jaman	*Eugenia* sp.	150	220
*28.	Kail	*Pinus excelsa*	70	120
29.	Karani	*Cullenia excelsa*	115	165
30.	Kokko	*Albizia lebbeck*	200	290
31.	Kusum	*Schleichera trijuga*	230	335
32.	Lampati	*Duabanga sounneratiodes*	150	220
33.	Lendi	*Legerstroemia parlflora*	190	275
*34.	Mango	*Mangifera indica*	100	145
35.	Mesua	*Mesua ferra*	260	375
36.	Oak (Assam)	*Quercus* sp.	280	405
37.	Oak (UP)	*Quercus* sp.	110	160
38	Padauk	*Pterocarpus dalbergioides*	190	275
*39.	Poon	*Calophyllum* sp.	160	230
40.	Sain	*Terminalia tomentosa*	160	230
41.	Salai	*Boswellia serrata*	120	175
42.	Sal (UP)	*Shorea robusta*	100	145
43.	Sandan	*Ougeinia dalbergioides*	170	250
44.	Silver oak	*Grevillea robusta*	120	175
45.	Teak (UP)	*Tectona grandis*	140	205
*46.	Toon	*Cedrela* sp.	150	220
47.	Uriam	*Bischofia javanica*	130	190
48.	White chuglam	*Taminalia bialata*	180	260

NOTE — The shear strength values of 125 and 150 mm nails are tentatively based on limited tests, that is 45 percent above those of 75 mm or 100 mm nails of 3.75 mm dia.

*Species require no pre-boring for nail penetration.

of bolts for design of bolted joints. This is sometimes referred in literature as 'diameter factor' (*see also* Examples 3 and 4).

TABLE 28 PERCENTAGE OF SAFE WORKING STRESS FOR CALCULATING BEARING STRESS UNDER COMMON BOLTS

L/d	Percentage of Parallel to Grain Conditions	Percentage for Perpendicular to Grain Condition
1.0	100	100
1.5	100	96.2
2.0	100	88.0
2.5	100	80.0
3.0	100	72.5
3.5	100	66.2
4.0	96	60.0
4.5	90	55.6
5.0	80	51.8
5.5	72	48.7
6.0	65	45.6
6.5	58	43.0
7.0	52	40.6
7.5	46	39.0
8.0	40	37.5
8.5	36	36.2
9.0	34	34.3
9.5	31.5	33.0
10.0	30.0	31.2
10.5		30.6
11.0		30.0
11.5		29.5
12.0		28.5

TABLE 29 MODIFICATION FACTOR FOR DIFFERENT DIAMETERS OF COMMON BOLTS USED FOR DESIGN OF BOLTED JOINTS IN PERPENDICULAR TO GRAIN CONDITIONS

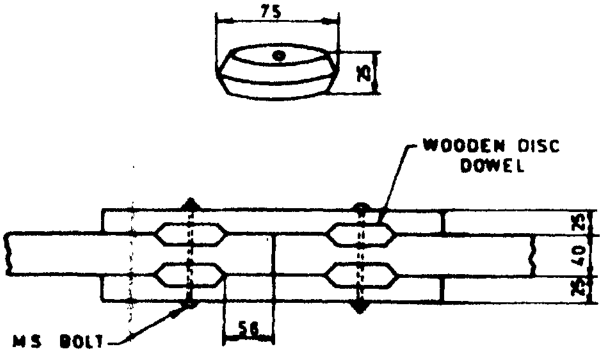
Diameter of Bolt in mm	Modification Factor (Also Known as Diameter Factor)
6	5.70
10	3.60
12	3.55
16	3.15
20	3.05
22	3.00
25	2.90

6.3.4 *Connectors*

6.3.4.1 *General* - As pointed out already in the earlier sections the timber joint is the most important aspect of any timber construction if transmission of stress from one member to another is to be done efficiently. When the joints are heavily stressed, the joint 'connectors' have been found to be the most effective, and in fact the development of these 'connectors' can be claimed to be the single factor which has revolutionized timber design and construction in the recent decades. The 'connectors' increase the area of the joint stress, thereby making it possible for full transmission and uniform distribution of stress around the joint area. Principally, they are of two types: (a) the wooden disc type, and (b) the metal type which are embedded partly in each of the faces of adjacent structural members, and used in combination with bolts of small diameters. At the Forest Research Institute, several tests have been carried out on these type of connectors and their behaviour. A few experimental structures have also been erected using these connectors. Some of these are discussed below. It appears no final aspects of standardization on the use of connectors have been developed so far. However, testing and evaluation of timber connectors has been standardized as per IS : 4907-1968 from which a general guidance may be taken for determining the sizes of connectors and their spacing also in a timber joint. Some useful publications on the use of connectors have been mentioned in the bibliography.

6.3.4.2 *Wooden disc dowel connectors*

a) These are circular hardwood discs, slightly tapered each way from the middle so as to have a shape of a double conical frustum. This is tight fitted into a pre-bored circular recess, half in each adjacent member of the joint. The members and the disc between them are held together by means of a bolt passing through their centres. The wood-working operations for preparing the discs and making corresponding circular grooves with appropriate bolt-holes are usually done by specially designed tools. If done by hand they require fair amount of skill to obtain a proper fit of the dowels in the matched circular grooves of the members of the joint. A typical example of joint with dowel disc can be seen in Fig. 15.



(All Dimensions in mm)

FIG. 15 TYPICAL EXAMPLE OF LENGTHENING JOINT WITH DISC DOWELS

b) The chief characteristics of the wood for making dowels are:

1) high shear strength,
2) high compressive strength parallel to grain,
3) good retention of shape under shrinkage and swelling forces,

4) low refractory characteristics,

5) high durability of heartwood, and

6) straight grained and free from other strength influencing defects like decay, splits, knots etc. Some of the Indian species found suitable for the purpose are babul, dhaman, irul, sissoo, sandan, axlewood, pinkado and yon. The discs are preferably made from quarter sawn planks of about 25 to 35 cm thick and seasoned to about 12 percent moisture content. They should be free from sapwood. However, where preservative treatment is required, this should be done properly. As the discs are generally hidden inside the structures, and not visible from outside, the condition of the disc in the course of life of the structure will not be known or easily observable periodically. In storage, great care should be taken to see that the discs do not in any way deteriorate. Sometimes, finished dowels are dipped in hot creosote for about an hour and stored for use. They should be well wiped and cleaned before fitting.

c) The wooden disc dowel in a joint is subjected to shearing at the mid-section and compression along the grain at the bearing surface. Hence equating the above forces:

$$\frac{\pi d^2 s}{4} = \frac{t_{cd}}{2} \quad \text{or} \quad \frac{\pi ds}{2t} = c$$

where

d = mid diameter of the dowel,

t = thickness of the dowel,

s = safe working stress of wood in shear along the grain, and

c = safe working stress for compression along grain.

6.3.4.3 *Metal connectors*

a) These have not made much advance as yet in timber engineering fields in India. Only some stray attempts seem to have been made on ring type of metal connectors. Further R & D efforts are still in progress in the country. In the United States alone more than sixty different types of metal connectors have been patented. Among the commonly used, the most popular types are split rings, toothed rings, male and female claw plates, spike grids, shear plates and clamping plates. They are made of different sizes to suit the different sizes of structural members and their characteristics and precautions to be taken in their use, etc, are usually published by the manufacturers themselves for the designer to make a proper selection.

b) Because of the different nature of materials of wood and metal which come in contact at the joint, it has not been possible to apply simple laws of mechanics and theory of elasticity to obtain exact distribution of stress in a joint. Hence dependence of test results is often the criteria for designing the joints with metal connectors in wood members.

c) In using the metal connectors in various structures some design considerations have been recommended in Appendix C of IS : 4907-1968. According to these, the allowable load for any joint using connectors should be calculated by multiplying the 'connector-factor', number of connectors in the contact faces and the working load for the species. The deviations from allowable loads can be in accordance with the following:

1) When allowable load is reduced due to edge, end or spacing distances, this should be determined separately for each connector and the lowest allowable load so determined should be applicable for all connectors resisting a common force in a joint.

2) Reduction in load due to the end, edge and spacing distances are not additive but co-incident.

3) Loads reduced because of thickness of members do not permit reduction in edge, end and spacing distances without further reduction of load, and conversely, loads reduced due to end distances, etc, do not permit reduction of thickness of members.

4) when more than one connector is used in the same contact face, they are to be placed symmetrically on the face of contact, taking care to see that the minimum of edge, end and spacing distances are permitted duly within the maximum space available. The ratio of connectors actually used to connectors required should not be more than 2. All connectors and bolts used should be of the same size, shape and material throughout the design. It would be necessary to place the connectors so that the angle of resultant load-to-grain should be more than 45° in order to get best performance, and that all loads or components thereof should act in the same direction on all faces. The maximum allowable load in the case of multiple connectors is the summation of allowable loads for each connector used, provided there are not more than three connectors on each contact face. For each additional connector, usually one-third of the allowable load of the same should be acceptable for calculation of the total

load. The minimum connector spacing (R) at any angle of loading (θ) is given by:

$$R = \frac{AB}{\sqrt{A^2 \sin^2\theta + B^2 \cos^2\theta}}$$

where

A = minimum connector spacing for the 0° loading, and

B = minimum connector spacing for the 90° loading.

The location of the connectors is determined by the intercept of the diameter of the ellipse whose axis in the direction of the grain is A and in the perpendicular direction is equal to B. In the case of two connectors in the same face placed as per the above formula the directions of the load and connector axis, coincide with each other but in case there are more than two, the axes of the different connectors may make different angles with the direction of grain (*see* IS : 4907-1968)

6.3.5 *Finger-Jointing*

6.3.5.1 These are essentially longitudinal joints which are slowly finding favour due to simultaneous development of strong, cold setting synthetic adhesives. The joints themselves have proved much stronger than the wood itself. At the ends of the timber members a set of uniform tapered projections are made by machines to fit into exactly corresponding V-shaped grooves in the opposite member. The strength of the joint naturally depends on the geometry of projection and the corresponding groove but no systematic studies seem to have been published as yet, which is a pre-requisite before any attempt on their standardization is made. However, this newly developing field seems to throw immense opportunities for utilizing short dimensioned stock for developing several types of timber structural units, both laminated and solid. This can well be one of the important directions for reducing wastage and for rational utilization of timber in engineering practices (*see* Fig. 16).

7. TEST METHODS FOR TIMBER STRUCTURES AND COMPONENTS

7.1 Introduction Although in the application of strength data and design of a timber structure, considerable amount of statistical considerations go in, and the data used has sometimes 95 to 99 percent confidence limits. There are factors particularly in fabrication and erection, which cannot be predicted at the time of design, to evaluate the exact chances that are being taken inspite of any codified rules and precautions. There are also factors of freak alignment of wood cells inside the wood material, atmospheric weather and changes in sorrounding humidity and temperature, and unpredictable behaviour of different types of components used in joints, etc, which may throw some elements of uncertainty. In consideration of all these, and also in view of no adequate experience in India of any extensive use of designed timber structures, the engineer often wishes to rely on some types of actual tests, whether of full scale in open air or model tests in laboratories. Tests on structural sizes of timber, other than those on small clear specimen, have already been dealt with under **2.1** and are covered in IS : 2408-1963. Other tests on components, full sized trusses, etc, developed in this country are dealt with in the following paragraphs. The full size tests are usually of two types: (a) destructive test in which case the behaviour of the structure as a whole is examined until it is loaded to failure,

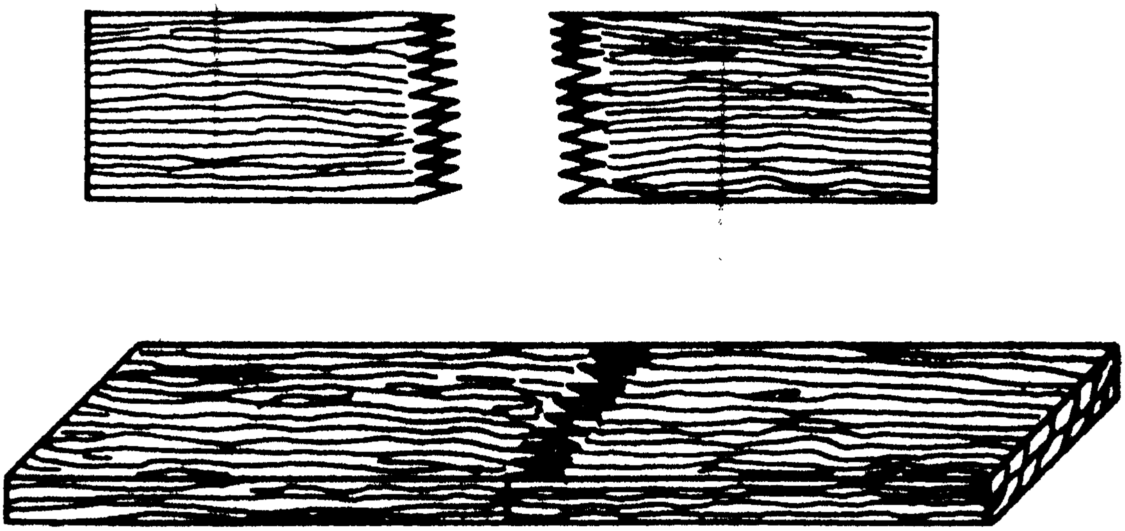


FIG. 16 FINGER JOINTS

and (b) proof test in which the structure is loaded lightly in excess of the design load, and the behaviour of the structure is examined over a length of period under actual service conditions or simulated under accelerated conditions.

7.2 Destructive Tests

7.2.1 *Objectives* The Forest Research Institute had conducted several destructive tests on various types of timber trusses and these have been reported in different publications (*see* Appendix B). The methods of loading and procedures of testing often varied depending on the objectives and the specific design. However, the destructive tests on nail-jointed timber trusses has been standardized in IS : 4924 (Part 1)-1968. The general principles outlined in this specification can be adopted for other types of trusses also. In this specification the main objectives of the tests have been identified as:

a) To determine the strength of members and joints under 'simulated' service conditions of loading assumed in design.

b) To measure maximum deflection of various node points of the bottom chord under loads of varying magnitudes and compare the same with the calculated and expected deflections and to determine the overall stiffness of the trusses.

c) To evaluate 'apparent' and 'actual' factors of safety. The apparent factor of safety is defined in IS : 4924 (Part 1)-1968, as the 'averge ultimate load taken by the truss at failure, divided by the total load for which the truss is designed', which for a nail-jointed timber truss has been fixed somewhat arbitrarily to be not less than 2.5. Similarly the actual factor of safety at failure is defined as 'maximum force produced at the point of failure of the member due to total ultimate load divided by the force the actual section can take at the point of failure' which for nail-jointed roof truss is somewhat arbitrarily fixed to be not less than 2.0.

7.2.2 *Procedures*

a) The trusses to be tested are to be fixed firmly on timber pillars or masonry pillars with sufficient clearance under the bottom chord for observation, loading, etc. The loads equivalent to 1.25 times the total design loads are applied in equal increments at all node points in the top and bottom chords, by means of hanging platforms to conform to the actually applied conditions in constructions. Lateral stability of the truss may be secured by placing a similar truss at suitable distance to simulate rigidity as in actual use through purlins, etc. Care should be taken to see that the truss under test receives only lateral restraint and not vertical restraints. Suitable dial guages or deflection measuring instruments may be placed at the centre of the bottom chord and also at lengthening joints to measure any slip in the same. These can also be placed at other relevant points where the deflection is to be particularly noted.

b) After 24 hours, the truss is completely unloaded and reloaded again up to failure by adding equal increments of loads with a time interval of five minutes to allow setting before noting the deflections. In case of ceiling loads, the bottom chord of the truss should be loaded up to design load. At each observation, the loads at heel points and at all node points, the deflection readings and time intervals should be carefully noted. The initial, final and residual deflections are to be calculated and the details of the failure should be clearly recorded. The 'apparent' and 'actual' 'factors of safety' are to be calculated as mentioned above. The allowable deflection, as calculated by the following formula, should be compared with the actual deflection observed

$$\Delta = \frac{\Sigma X}{E} \text{ [\textit{see} IS : 4924 (Parts 1 and 2)-1968]}$$

where

Δ = allowable deflection in cm,

$X = \frac{N.F.U.L}{A}$

E = modulus of elasticity of timber in kg/cm^2,

N = number of planks in a member,

F = force induced in a plank due to design load in kg,

U = force induced in the members of the truss due to unit loading in kg placed where deflection is required to be found out,

L = Length of the member in cm, and

A = total sectional area of the member in cm^2.

7.3 Proof Tests

7.3.1 *Objectives* — In these type of tests known as proof tests, the main objectives are to observe the joint slips (instantaneous deformation) and creep in timber roof trusses under prolonged loadings, and under simulated service conditions. Thus the stiffness of members and joints is determined instantaneously, and over a long period as a whole. This would also help to decide on the provision of initial camber in the bottom chord during fabrication stage. These studies will also provide studying the effects of variables due to normal building openings.

7.3.2 *Procedures* — The general procedures required for supporting loading arrangements, obtaining lateral stability, and measuring deflections are, in general, same as described in **7.2.2**. The test loads are kept constant either until a permanent set is reached or for a period of one year whichever is less. The deflections at the centre of the bottom chords (or at any other place where it is specifically required) are recorded everyday. A record should also be maintained of diurnal and seasonal variations of atmospheric conditions. In the end a graph is plotted between deformation and time. In IS : 4924 (Parts 1 and 2)-1968, an interpretation is given that the initial instantaneous deflection, as usually observed in the 'time-slip' curves, is due to joints and further deflections are due to creep of timber. This may be taken only as general guidance and more sophisticated methods of measurements at the joints and in timber members will indicate more accurate picture. It can be possible that the initial instantaneous deflection can be partly due to mechanical slip at the joints and partly due to reversible elastic deformation of members. Further increase in deflection with time under the same load is also to be interpreted in terms of its recoverability whether the creep is primary or secondary, or whether it is a phenomena of further slip in joints due to gradual realignments in the forces and members caused due to initial instanteneous slip. Normally no creep, whether primary or secondary, should occur in any member in view of the fact that due care was taken in deriving the working stresses.

7.4 Tests on Joints and Connectors

7.4.1 As the most significant advances in timber design have resulted through development of metal connectors such as split rings and shear-connectors, it has become necessary to know the detailed functional aspects of these connectors. For this purpose, in order to evaluate the main characteristics of such connectors, IS : 4907-1968 has been prepared to standardize the conditions and procedures for testing these connectors so that their characteristics are comparable. These tests have also served as a basis for developing design criteria for their use, and also for determining the effects of various influencing factors, such as species of wood, thicknesses and widths of members, end margins, spacing, and moisture content of wood.

7.4.2 For purposes of the above tests, three groups of species are chosen; Group A species which differ in compressive strength from that of 'sal' by ± 30 percent, Group B species which differ from compressive strength of 'teak' by ± 30 percent and Group C species which differ in compressive strength from 'chir' by ± 30 percent. All species are to be used in green condition and also at 12 ± 1 percent moisture content. The dimensions and the distances of connectors from edges and ends of test pieces in the tests parallel and perpendicular to grain are required to be as given in Fig. 17. The rate of load application should be uniform and continuous at the rate of 1 mm/min until the maximum load is reached. From the load-slip curves, the slip at proportional limit also is noted. In each case the connector factor (CF) is calculated as below and is used in determining the allowable load.

$$CF = \frac{JF}{mn}$$

where

JF = joint factor, which is the ratio of percentage of load developed to the full load which the member may take without the joint (The loads may be taken either at the maximum load for failure, or at proportional limit of the slip, or at the specified slip, as required for comparison or design);

n = number of connectors tested in each contact face when multiple connectors are used for tests in specific designs; and

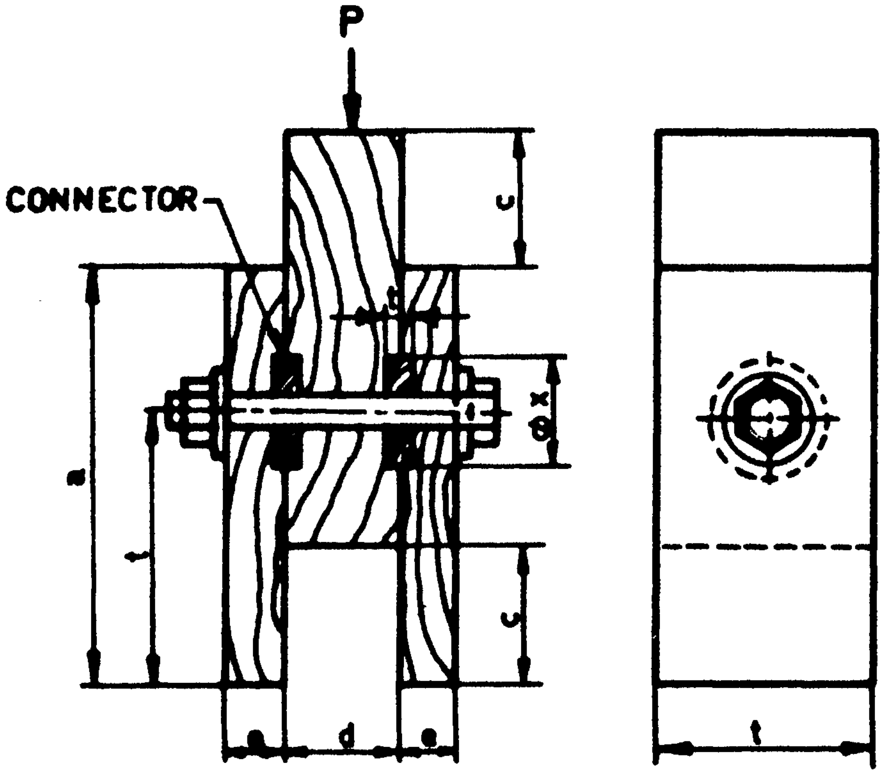
m = number of contact faces.

7.4.3 Whenever special tests are required in connection with design of a particular timber structure, additional information on minimum and maximum end-distances and edge-distances for the required working load both for tension and compression loadings would be useful. Besides, if a chart is drawn between the percentage of full load at various edge distances, and for various inclinations of load-to-grain, then it may be seen that the relationship between such percentages of full load, and edge distances is linear and separate for different angles. Similarly separate charts for end distances would also be useful to decide on final placing of the connectors with reference to the sizes of members, their inclinations and loads. Where multiple connectors are used, the relative spacing between the connectors would also be required. Necessary precautions in the use of such connectors have already been described in **6.3.4.3**(c).

8. FABRICATION, CONSTRUCTION METHODS AND PRECAUTIONS

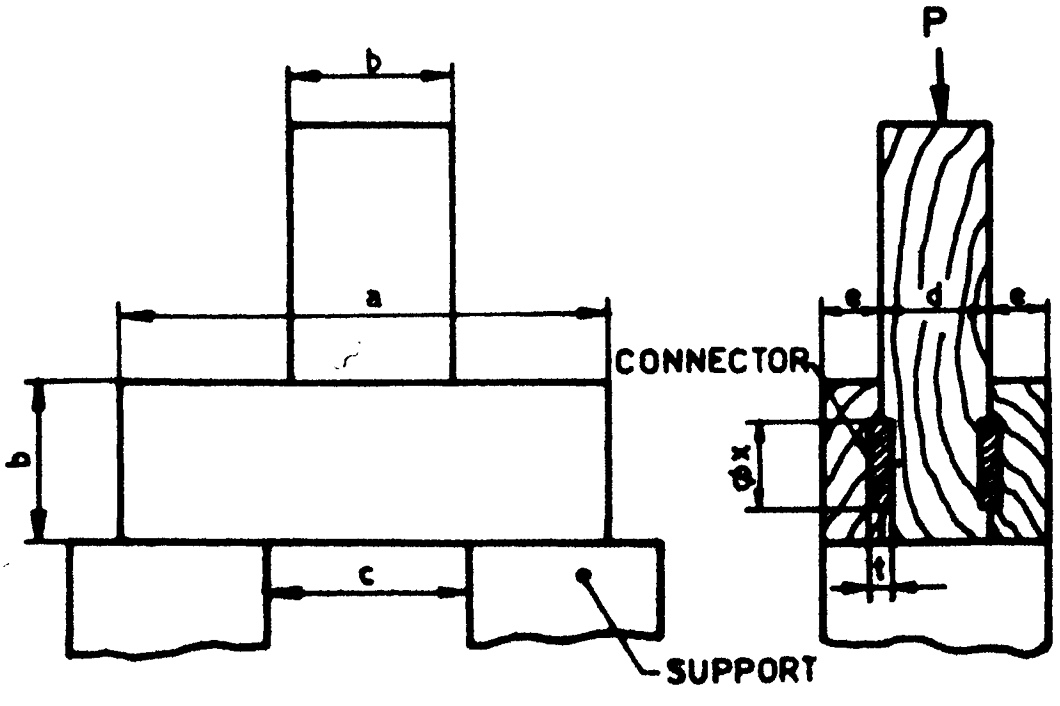
8.1 General

8.1.1 It has been amply brought out in earlier sections that the safety of timber structures depends not on merely safe design or selection of careful material but equally on the care taken in fabrication, construction and erections. There are no separate standards on the subject but relevant clauses are available in respective standards. Some of essential features of fabrication have already been discussed under **6.2** and **6.3**. Sometimes the design takes care of the fabrication and construction difficulties, though it is not always possible to do so. In the foregoing paragraphs, only some of the general methods employed for fabrication and erection of different



$a = 3c$, $b \nless 2x$, $c \nless 1.75x$, $d = 2e$, $e \nless t$ and $f = 2c$

17A Strength Test Parallel to Grain



$a = 3b$, $b \nless 2x$, $c = 1.1b$, $d = 2e$ and $e \nless t$

17B Strength Test Perpendicular to Grain

FIG. 17 STRENGTH TESTS OF CONNECTORS PARALLEL AND PERPENDICULAR TO GRAINS

types of structures are briefly discussed. In the country, some claims are often made that timber fabrication does not need highly skilled labour and simple tools are normally sufficient which reduce the cost of labour. These may be true as compared with workers dealing with other materials of construction. However, within the same field, the wood worker employed on fabrication of timber structures, though working with somewhat similar tools should be one who can understand some of the implications of wood working particularly if he goes beyond the permissible tolerances of working. He should also be familiar with behaviour of timber in question under the action of different tools he employes, and how best to get the finish nearest to the constructional design. That is, he should be well acquainted with the working qualities of the species. He should know, for example, how the several deviations of grain in a long member may create any eccentricity and deviate from the assumption that the central line of force passes through the axis of the member. Thus, even if semi-skilled labour is occasionally employed, a perfect supervision is essentially called for to coordinate the different operations carefully and accurately. At all stages of production of structural units, their fabrication, etc, it is essential that due care is taken to stack the timber neatly and properly to avoid contamination or damage by exposure.

8.2 Fabrication and Assembly

8.2.1 At present there is no organized production of structural units in any factory for mass supply in India. Whenever a large number of units of the same type are required, stray efforts are made for labour saving methods locally and introduce some economy. However, in the timber engineering practices there is some awareness for developing modular systems for introducing coordinated economy in handling, transport, fabrication and erection as is very common in other developed countries. It is recognized that conventional timber structural designs and constructions are not found suitable for prefabricated modular design. Instead of using long length and thick sections of timber, as in earlier days, new tendency is developing to use shorter lengths with appropriate fasteners and simple jointing devices such as nail-jointing techniques. The modular coordination contemplated is on the basis of basic module 1M equal to 100mm, corresponding to NBC (Part VI). Other recommendations therein, are also easily applicable to timber structures. Accordingly, the dimensions of modular door apertures are of 20, 22 and 24 m in height, and 7, 8 and 9 m in width. Similarly for window apertures 12 and 22 m are the heights, and 9 m is the width. However, the panel products sold in this country, having been largely produced on imported machinery, are still sold and demanded in the market on the basis of 8′ X 4′. Continuous and rigorous efforts are still being made at least to rationalize the above dimensions into standard metric equivalents. Usually the various components, such as timber cleats, splicing plates, boards and required notches in beams are first prepared in workshops according to relevant drawings and given the necessary treatments also. Other hardware like nails, bolts, clips, fasteners and corresponding drill bits and chisels for pre-boring and chipping operations are kept ready for different stages of fabrication and assembly. Bolt lengths should be such that extra threads would be available for tightening to compensate for permissible variations in the sizes of members and for tightening after any shrinkage occurs. If fabrication is accurate, assembly becomes comparatively simpler. Usually assembly is recommended as near as possible to the erection site.

8.2.2 *Fabrication Machines and Tools*

8.2.2.1 Normally an ordinary saw mill, woodworkshop and wood working tools form the major part of the equipment for fabricating timber structural units. These are the band saws, the circular saws for ripping and cross-cutting, jointers, planners, moulding machines, boring machines including mortizing and tennoning machines. Among the hand tools, the hand planes, chisels, augers, borers and mallets are required. In addition to these, appropriate glueing and pressing equipment also would be needed, where necessary. However, where special joints are to be made like, dowel disc connectors and finger joints, special types of machines may be sigged up, or some of the above machines may be suitably modified for the needed accuracy in fabrication. The Forest Research Institute has developed a few of them as described below.

8.2.2.2 A finger jointing machine has been developed consisting of high speed steel cutters, mounted on a horizontal spindle. It rotates at a very high speed as are most of the other woodworking machines. When the plants are fed, end on, through a sliding platform, the V-shaped finger grooves of desired dimensions are made. Two members are then joined end to end by interlocking, glueing in the grooves, and applying the required pressure. In some foreign countries, all the above processes are automatically done continuously and in proper sequence so that production costs are kept at a minimum.

8.2.2.3 A modified drilling machine which can cut circular recesses in timber and which can prepare the required disc dowels with tapers has been developed at the Forest Research Institute, Dehra Dun, for 76 mm diameter and 25 mm thickness. This has been successfully used for fabricating trusses of different spans.

8.3 Light and Heavy Constructions

8.3.1 Although, in India, examples exist of several types of timber constructions, such as timber trusses for a variety of roofs, lamella constructions, bridges towers, poles and posts, there has been no specific effort to standardize what may be classified as light constructions and to draw a distinction between them. As already discussed under **6.2** and **6.3**, the different types chosen to meet the heavier loads and increased spans as per the needs of the design may fall under the definition of heavy constructions. Sometimes multi-planner constructions (that is, with two or more solid members) are preferred for heavy loads and longer spans as compared to mono-planer constructions (That is, with single solid members), as the former are stiffer than the latter. They allow greater stresses in multiple shear as against the spice plates in mono-planer constructions. However, in some of the western countries the light constructions treated slightly different from heavy constructions, as in the latter the options are less compared to the former.

In light framing, generally it is not necessary to develop the full strength of all members at the joints as it is felt that the load bearing members are seldom stressed to maximum capacity. However, it is essential that the joints must be amply strong and rigid to transmit all the loads. The assembly and fabrication aspects become somewhat simpler. In heavy timber framing the weakest point is always identified, and it is often recognized as the joint, and so its design and fabrication is such as to develop the full strength of the connecting members. To a large extent the framing carpenter should be fully aware of any shortcomings in fabrication that may reduce the effectiveness of the joint. In general, where it is possible to secure chords of full lengths and avoid joints, it may be better to use long timbers even at the expense of increased costs. Light construction material has greater suceptibality to weather conditions than those intended for heavier constructions. Particularly the angles between various members may get distorted under unfavourable circumstances such as bad weather and over hanging loads if not properly stacked. Care should be taken to avoid these situations.

8.3.2 for making trusses and nail joints it is the usual practice to make the layout of the structural unit on a level platform ground, marking clearly the widths of various members. Hardboard or plywood templates of various sizes, as required in the drawings, must be prepared first to indicate the nail or bolt positions. These can be used to transfer the markings to splice plates of the members, and then necessary pre-boring is done on them as required. First a few nails are driven partly and temporarily at various points to form a complete skeleton and check the profile. Finally, the nails or bolts are carefully fixed from both the faces as per the drawings.

8.4 Erection and Fixing

8.4.1 Erection equipment are either locally improvized by pulleys or special equipment obtained on the basis of the loads to be lifted to the heights, and the working spaces for erection. Roof-framings often present some hazards after erection has commenced, and as the joists, etc, get installed in the respective places. Adequate bracing of ballies, etc, are recommended for keeping all the columns firmly in position. In all erection stages, it should be ensured that the minimum of erection stresses come into play as usually these are not provided at the time of design. After erection and fixing, all joints should be carefully checked and bolts tightened, wherever necessary. The structure should be periodically inspected and its stability should be ensured under the varying environmental conditions.

8.4.2 If any member gets damaged either in erection and fixing or in subsequent use, it should be comparatively easier to replace or reinforce in timber structures than in other types of structures. Consistent with the economy, adequate facilities should be readily available for all such eventualities.

9. WOOD FINISHES, PROTECTION AND MAINTENANCE

9.1 Wood Finishes

9.1.1 Like any other material of construction wood also requires to be appropriately surface coated and periodically maintenance measures are taken in order to obtain the best life from the same. The process commonly known as 'wood finishing' consists of first preparing the surface and then application of a continuous layer of a coating on the surface of wood. The principal objectives in this are:

a) protection to the surface of wood against some damages; and

b) Obtaining the required appearance or

Sometimes both the above would be needed, and sometimes the main emphasis would be on one or the other of the two mentioned above. Sometimes the surface properties like abrasion, hardness, etc, also are intended to be improved which can also be classified under 'protection' against possible mechanical damages.

It should, however, be remembered that wood finishing is not a preservation technique as wood preservation against biological damage is commonly understood. Although wood finishing has been in practice from times immemorial, the exact mechanism of adhesion of the coated film to the wood, is still a matter of considerable theoretical discussions. But mainly, two aspects of the mechanism are recognized:

a) 'mechanical adhession' by which the applied coating enters the minute cavities on the surface of woods, gets dried and hardened and provides a strong layer of film on the top; and

b) 'specific adhesion' by which there are interacting chemical forces between the surface of wood and the chemical constituents of the applied coating resulting in a smooth continuous film on the surface of wood.

Thus the former is dependent somewhat on the physical nature of wood surface and the latter depends somewhat on the chemical nature of wood surface . For these reasons, preparation of wood surface (such as a sanding or applying suitable pre-coats) becomes an important operation before any surface coating is applied, and the degree of such a finish varies from species to species.

9.1.2 *Type of Wood Finishes and Basic Materials* — From the point of drying there are principally two types of coatings:

a) which dry through irreversible chemical reaction, and as such cannot be brought back to the original condition; and

b) which dry by evaporation of the solvent and so can be brought back to the original condition by the same solvent.

Sometimes a combination of (a) and (b) occurs in which the evaporation of solvent causes the initial set and then the oxidation of oils or polymerization of resins set in. As the nature of oil or resin is thus altered, so the reaction is irreversible. The primary basic materials used in wood finishes and their functions are the drying oils and resins (which provide the continuity in the film), the pigments (which provide the desired colour and ensure capacity), and the volatile solvents (which regulate the consistency). Some of the secondary materials are plasticisers and driers which are employed, when necessary, to impart special properties like removing of brittleness, increasing hardness, etc. The principal classes of wood finishes are the following:

a) *Shellac* — This is made by dissolving the oxidation of lac insect (*Tacherdia lacca*) in alcohol or alkaline water. It forms a quick drying permanent film of low strength.

b) *Varnishes* — These are large groups of somewhat transparent finishes with varying properties. They are usually prepared from natural or synthetic resins, mixed with drying oils and volatile thinners. Other chemicals are also added, sometimes to achieve the keeping qualities and easy spread. They dry quickly by evaporation of thinners, oxidation of oils or polymerization of resins.

c) *Lacquers* — These are the surface coatings used whenever shining appearances are required, and so they are often used for art objects and some types of decorative panels. Formerly these were obtained from plant origin (*Rhus verniciflua* trees grown in Japan and China) and were sometimes refered to as 'oriental lacquers'. Presently many synthetic lacquers are available. These are obtained by dissolving resins and cellulose esters (nitrates) in different solvents. They are very quick in drying clearly transparent, glossy, and generally unaffected by temperature or mild acids and alkalis.

d) *Paints* — These are purely mechanical mixtures of pigments and vehicles, thinners, driers and varnishes, etc. The required colours may be obtained from some inorganic salts as zinc oxide or lead carbonate for white; lead chromite or ferrous oxide for yellow; lead oxide for orange; ferric oxide, lead-oxide, some mercuric compounds for red; chromic oxide for green, lead sulphide for black, etc. In earlier years organic colouring materials of natural origin have also been used such as blues from indigo, etc. For various IS colours, a reference may be made to IS : 86-1950 and correspondingly relevant standards for obtaining such colours.

e) *Enamels* — These are various types of varnishes or lacquers together with some opaque pigments for colour in order to obtain improved wearing properties of the coated film. They give smooth and tough surfaces.

f) *Fillers and sealers* — These can be either coloured or uncoloured as desired. They are used primarily as base material to prevent excessive penetration of subsequent coating and provide for its easy spread.

A number of commercial wood finishes are now available in Indian markets. Before applying the same on any wood surface, unless their ingredients and their effects are well known, it would be useful to check in each case the relative claims of various commercial wood finishes by actual field trials, and wherever possible, by accelerated weathering tests in laboratories with requisite facilities. Some similar tests may also be done at site on small sample surfaces. However, a knowledge of various factors which influence wood finishes would help the selection of the appropriate wood finish in relation to the species of timber actually in use. There are also a number of Indian Standards available for different types of wood finishes as mentioned in **9.1.4**.

9.1.3 Factors which influence wood finishes are as follows:

a) *Nature of wood* — A coating which is properly and uniformly done, is not generally affected in its early life by the kind of wood, but after some ageing under different types of exposures, etc, the nature of wood determines the rate of disintegration of the coating. In soft woods, particularly where its resin content is high and in which formation of early wood and late wood are distinct, there will be some cracking of the coating and damages, particularly in such coatings which have lost their toughness due to ageing, they adhere only mechanically to the late wood on account of its comparatively better dimensional stability. In hardwoods, coatings remain stable comparatively for longer periods in lighter woods than in heavy and harder woods. Diffused porous woods are said to hold paints better than ring porous woods, and so also sapwoods provides better mechanical adhesion than the heartwood.

b) *Extractives in wood* — Leaching of extractives may sometimes have an adverse influence on surface coatings, but otherwise their presence as such in the wood itself is not always unfavourable. It is the nature of extractives that is more important than the amount of extractives because of their chemical behaviour.

c) *Physical properties* — Unless properties like thermal expansion, water absorption of the films, etc, match also with similar properties of wood, certain amount of incompatability, may arise. Any action of ultraviolet radiation may disintegrate some of the paints. Commercial paints are therefore generally prepared for wide spectrum of variations of physical properties. The moisture protective effectiveness of the film is calculated by:

$$E = \frac{(A - B) \times 100}{B}$$

where

E = moisture protective effectiveness,

A = gain in the weight of specimen without the finish, and

B = gain in the weight of specimen with finish when both the samples are exposed to dampness under identical conditions initially as well as during the experiment.

9.1.4 Relevant Indian Standards available for some types of wood finishes are indicated below. It is not mentioned clearly whether the recommendations made in the specifications are applicable uniformly to all species of wood and, if not, the species characteristics may sometimes introduce relevant changes.

IS : 75-1973	Linseed oil, raw and refined (*second revision*)
IS : 155-1950	Ready mixed paint, matt-black, for use on wood
IS : 162-1950	Ready mixed paint, brushing, fire resisting, sillicate type for use on wood, colour as required
IS : 337-1975	Varnish finishing, interior (*first revision*)
IS : 347-1975	Varnish, shellac, for general purposes (*first revision*)
IS : 349-1981	Lacquer cellulose, nitrate, clear, finishing, glossy for metal (*first revision*)
IS : 524-1968	Varnish, finishing, exterior, synthetic (*first revision*)
IS : 3536-1966	Ready mixed paint, brushing, wood primer, pink
IS : 3585-1966	Ready mixed paint, aluminium, brushing, priming, water resistant, for woodwork

The important standard which is often referred, where wood finishing is to be done in a standard way is IS : 2338 (Parts 1 and 2)-1967. Part 1 deals with operation and workmanship; and Part 2 with schedules for different types of final finish required, such as enamel, oil gloss, flat, varnish or grained work separately for exterior and interior new wood work. The operations and workmanship are discussed below.

9.2 Application Methods

9.2.1 Before applying any coating of wood finish on the surface of wood, the same must be properly seasoned and sanded to the requisite moisture content and smoothness, and cleaned well. Whenever necessary a primary coating is given and when it becomes dry the main wood finish is then given in one or two coatings as may be required. Generally the prime coating and subsequent coatings are applied by brush for all wood works in position in various buildings and structures. When spraying is adopted care should be taken to see that the spray does not fall on unwanted areas. While careful spraying gives compartively fine and thin uniform coatings, there may be some wastage caused due to the spray falling beyond the required area of the wood work. But spraying is comparatively quicker method of application than brushing for the same area and for the same finish required. Spraying is invariably adopted when finishing is done on wood work components individually in the prefabrication workshops. For greater details on selection of coating materials, priming stopping, filling and application of undercoats, reference may be made to IS : 2338 (Parts 1 and 2)-1967.

9.3 Maintenance

9.3.1 Maintenance of wood work in any building or structure is as important as design, fabrication and erection. Inspite of many precautions taken for increasing the dimensional stability of wood and decreasing the causes of decay, there may still be some factors, particularly in the structure of wood, which have not received full attention. These are mainly the differential physical properties arising out of non-homogeneity of wood structure. Some type of deterioration is also attributable to inadequate treatment processes in the initial stage or even due to inadequate measures provided for proper maintenance. As such, atleast for some years in the initial stage, periodical observations are necessary and the appropriate remedial measures are to be taken.

9.3.2 . One of the common observations in wood work in buildings anu other structures is loosening of joints caused due to shrinkage. Swelling of wood also may cause enormous stresses at the joints resulting in some distortions. For this, appropriate measures to tighten the joints or remove the excess material under swelling should be undertaken. If any excessive deflection or twisting or bowing of members is observed, or the alignment of wood work is distorted, necessary repairs should be done at the earliest unless they are not of immediate danger and there is a possibility of the defects getting removed naturally in course of time. Timber structures are usually easy to repair. The repairs are generally of the type of reinforcing the joint or any weakened member. Sometimes there can be also replacement of decayed portion of wood. Consistent with the costs involved all outside pieces, if damaged, can be easily removed and replaced, but all the interior pieces should invariably and preferably be reinforced only.

9.3.3 Much of the wood work in the interior of buildings does not require recoating with wood finishes as periodically as the exterior and exposed wood surfaces require. All such exposed surfaces, require every year repetition of the surface coatings as originally done. When the coating becomes too thick, and scales start coming off, or when a differently coloured coating is required, it may be necessary to first remove the original coatings either by controlled flame, or by boiling the pieces of wood work (like door and window shutters) in alkaline water, cleaning the surface thoroughly thereafter, and repainting all over again. Normally all exposed wood surfaces should be given water repellent paints and repeated every few years. There are examples in India of linseed oil treatment alone having protected timber for quite a long time.

IS : 2338 (Part 2)-1967 gives in a tabular form recommended practices for cleaning and painting periodically when the condition of the original painted surface shows blistering, cracking, checking or chalking. Whenever blistering or cracking is heavy and deep, it is recommended that the paint should be removed completely to base wood, and entire schedule should be followed again.

9.3.4 If inspite of all precautions, insect attack is detected in its early stages, immediate corrective steps should be taken to clean the infested portion and give liberal coating of paints or polish with preservatives. If necessary, slanting holes can be drilled in the wood to fill them up completely with the preservative. Simultaneously care should be taken to eradicate the sources where insects are breeding. In the case of termites, the termite-mound should be destroyed, and the soil properly treated with chemicals. The soil, or the floor around which wood is embedded, should be periodically treated with suitable preservatives. Sometimes fumigation would help killing of any existing infestation and prevent its spread but this should not be considered as a permanent way of preventing any future infestations. In India, a number of pest control organisations have recently come up to undertake these jobs as required.

10. FUTURE POSSIBILITIES

10.1 Introduction - At several places, in earlier sections, it has been brought out how, in several areas, there is lack of adequate experimental data, and there is no development of accurate theory, resulting in extra safety measures that are required to be taken in design and construction of timber structure. Also owing to inadequate supply of conventional and well known timbers, a need has arisen for use of not only alternate species but improved products of the same and for which considerable developmental activity is still in progress. With rapid strides in trade, and industrial patterns of the country, a need has been felt for increasing use of timber and timber products inspite of many competitive materials coming up. Here it is proposed to review some of the trends and developments, and project future potentialities in timber engineering.

10.2 Glue-lam Engineering

10.2.1 Of the several directions in which developments are taking place, glue-lam structures in timber engineering is the most promising with a high economic and technical potential. Laminating planks of wood up to generally 5 cm thick with the grain of all planks of wood running in the same direction and with the help of newly available cold setting commercial adhesives, almost any shape and size of structural component can be developed. This has been particularly useful in arches and curves in members. In this process it has been possible to utilise low grade timber in areas of lower stresses like the neutral axis region of beams and high grade timber in areas of higher stresses like the extreme zones of beams. The rigidity obtained due to interlayer of glue lines (which is always stronger than timber) between the planks, and at various joints is highly desired factor in timber structures. However, considerable amount of research work seems necessary particularly in the glueability characteristics of several Indian species used for structural purposes. Engineering tests on different types of glue-lam structural units would help development of working stresses for the same. It would also be possible to develop the necessary modification factors for permissible stresses depending on the number and nature of laminations and their direction (that is, grain orientation) to the induced loads. When once a structural unit like a beam or column is developed, and its overall strength is determined, it can be used in the structures by the same design methods as in normal cases. However, it should be possible for designing and preparing a laminated unit of required properties, from the properties of individual laminations which may be required to be determined. The mechanical behaviour of the composite material can be computed from the strength and geometry of individual laminations.

10.3 Plywood Engineering

10.3.1 Unlike in glue-lam product the grain of timber in alternate layers of plywood runs in directions perpendicular to each other. Varieties of plywood are produced in India, and already a fair amount of progress is made in the application of plywood for structural engineering purposes. As in this Handbook only solid timber was intended to be covered, the development in the field of plywood engineering (that is, structural application of plywood) has not been covered. Plywood has been used as stressed skin panels for walls and ceilings web beams, arches, panels, portal frames and gussets. Plywood has also been used in builtup beams such as I-beams and box type beams. Some attempts are also made for developing shell roofs and domes and folded plate roofings with plywood because of its uniform strength in perpendicular directions, and its light weight. The use of plywood in big drums, grain silos, farm houses, etc, are well known. However, it appears that some systematic studies on computation and evaluation of strength of plywood on the basis of strength and thickness of individual veneers is still required to be pursued in India. Although rigorous tests are available [*see* IS : 1734 (Parts 1 to 2)-1972] for determining strength of plywood, evaluation of appropriate working stesses and standardization of plywood constructions would further help rapid developments in plywood engineering. Studies are required to be undertaken on the efficacy of various types of joints with plywood. Use of special types of fastening hardware, such as nails, staples, screws, bolts and clips are currently under investigation. It is known that plywood has shown very good holding power with these in a direction perpendicular to its surface. Edgewise resistance to withdrawal of nails is somewhat lower but still comparable to that of solid wood. For this purpose special types of fasterners like grooved nails and special type of screws are coming into gradual use.

10.4 Other Forest Based and Biological Materials

10.4.1 Besides timber which is a major product from forests, other minor forest products like bamboos and canes are also available for structural and non-structural purposes in building construction. The use of bamboos, as an important constructional material for rural dwellings, is well known in India, Japan and many other South East Asian countries. Bamboos have also been used for developing variety of building boards. Recently considerable developments have taken place in using bamboo for reinforced concrete as an alternate to steel at a lower cost. This has been particularly useful in low cost structures. The averge tensile strength of bamboos varies from 1 400 to 2 900 kg/cm^2 and this high strength value has naturally attracted its use for reinformcement in concrete. At present the same principle, as for steel reinforced concrete, is employed for design of bamboo reinforced concrete structural units, but a setback is observed due to shrinkage and swelling of bamboo resulting in weakening of bonds and development of cracks. Split bamboo with surface treatment for increasing the bond, and with properly designed meshwork for reinforcement seem to give good hopes of increased use of these techniques (*see* Fig. 18). Considerable amount of labortory and field data seem to be required before standardization can be attempted and regular engineering practices can be codified.

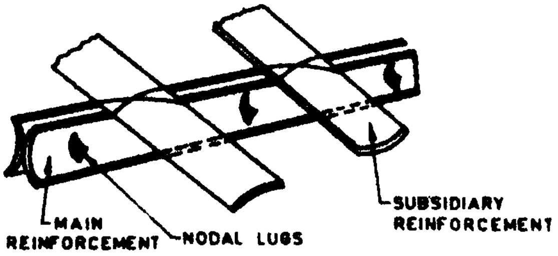


FIG. 18 DETAILS OF BAMBOO REINFORCEMENT

10.4.2 Besides making plywood with wood veeners a variety of panel products have come in the market like hardboards, particle boards and bamboo boards. Some of the grasses and reeds, bagasse, cereal stalks, pine needles, and a variety of raw materials have also been used for preparing different sorts of panels and boards for building purposes. In some of the western countries, some of these boards have been widely used in standard building constructions. In some countries particle boards of different thicknesses have already come into structural use in buildings.

However, standards do exist at present for producing some of the above materials for non-structural end use purposes. Considerable amount of efforts in data collection and development of structural designs are required in the country before attempting standardization. However, wood wool building slabs according to IS : 3308-1981 have come into prominent use for ceiling and acoustic purposes.

10.5 Prefab Techniques

10.5.1 If timber engineering is to remain economical, in the face of increasing labour costs and specialized hardware, adhesives, etc, importance of prefabrication in workshops cannot be overlooked. As already explained in earlier sections, there are at present no special prefab techniques developed in India for mass production of timber structural units, but only the normal wood workshop facilities are utilized for production of similar structural components all together at a stretch. However, it is required that for mass production of any standardized structural units such as trusses, or built up columns for ready use, there is a need of special types of jigs, fixtures, boring machines, nailing machines, glueing machines, etc. Such types of machines for multiple borings for connectors, or quick insertion of gangnails (multiple nails in one plate) are in common use in other countries. To develop these machines and techniques, not only a demand for standard timber structural units is required to be built up but considerable R&D efforts are required to be put in for optimum working conditions. There appears to be considerable potential for development in this field in view of the present tempo in rural development schemes and urban housing programmes on a large scale.

10.6 Computer Techniques

10.6.1 Just as in many other fields of science and technology, computation of data and programming a series of mathematical operations for obtaining the solutions are required, so also in the field of timber industries. Also in structural uses of timber, it has now become possible to introduce computerization. Some of the conversion and saw-milling operations, grading, etc, are now being done in other countries by computer techniques so that a log fed at one end automatically comes out at the other end in the form of appropriately sized and graded converted material for ready use in structures. Either by colour indication or by actual printing arrangement on the member, the material at the other end will be classified into use within specific range of working stresses for beams or columns or boards, etc, as the case may be, although it appears a need of this type would arise in India only when timber structures become popular manifold than what it is at present. R&D efforts in this direction may start to keep pace on one hand with the developments in other countries and on the other to evolve indigenous systems by which unknown factors in timber utilization may fall beyond the judgement and discretion of individuals.

APPENDIX A

(*Clause* 1.6)

INDIAN STANDARDS USEFUL FOR TIMBER ENGINEERING

IS : 190-1974	Specification for coniferous sawn timber baulks and scantling (*third revision*)
IS : 218-1983	Specification for creosote and anthracene oil for use as wood preservatives (*second revision*)
IS : 287-1973	Recommendations for maximum permissible moisture content of timber used for different purposes (*second revision*)
IS : 399-1963	Classification of commercial timber and their zonal distribution (*revised*)
IS : 401-1982	Code of practice for preservation of timber (*third revision*)
IS : 707-1976	Glossary of terms applicable to timber technology and utilization (*second revision*)
IS : 851-1978	Specification for synthetic resin adhesives for construction work (non-structural) in wood (*first revision*)
IS : 852-1969	Specification for animal glue for general wood working purposes (*first revision*)
IS : 876-1970	Specification for wood poles for overhead power and telecommunication lines (*second revision*)
IS : 883-1970	Code of practice for design of structural timber in buildings (*third revision*)
IS : 1003 (Part 1)-1977	Specification for timber panelled and glazed shutters: Part 1 Door shutters (*second revision*)
IS : 1003 (Part 2)-1983	Specification for timber panelled and glazed shutters: Part 2 Window and ventilator shutters (*second revision*)
IS : 1141-1973	Code of practice for seasoning of timber (*first revision*)

IS : 1150-1976	Trade names and abbreviated symbols for timber species (*second revision*)
IS : 1326-1976	Specification for non-coniferous sawn timber (baulks and scantlings) (*first revision*)
IS : 1331-1971	Specification for cut-sizes of timber (*second revision*)
IS : 1609-1975	Code of practice for laying damp proof treatment using bitumen felts (*second revision*)
IS : 1634-1973	Code of practice for design and construction of wood stairs in houses. (*first revision*)
IS : 1642-1960	Code of practice for fire safety of buildings (general) : Materials and details of construction
IS : 1643-1960	Code of practice for fire safety of buildings (general) : Exposure hazard
IS : 1708-1969	Methods of testing small clear specimen of timber (*first revision*)
IS : 1900-1974	Methods of test for wood poles (*first revision*)
IS : 1902-1961	Code of practice for preservation of bamboo and cane for non-structural purposes
IS : 2191 (Part 1)-1983	Specification for wooden flush door shutters (cellular and hollow core type): Part 1 Plywood face panels (*fourth revision*)
IS : 2191 (Part 2)-1983	Specification for wooden flush door shutters (cellular and hollow core type): Part 2 Particle board and hardboard face panels (*third revision*)
IS : 2202 (Part 1)-1983	Specification for wooden flush door shutters (solid core type): Part 1 Plywood face panels (*fourth revision*)
IS : 2202 (Part 2)-1983	Specification for wooden flush door shutters (solid core type): Part 2 Particle board and hardboard face panels (*third revision*)
IS : 2203-1976	Specification for wooden cross arms (*first revision*)
IS : 2338 (Part 1)-1967	Code of practice for finishing of wood and wood based materials: Part 1 Operations and workmanship
IS : 2338 (Part 2)-1967	Code of practice for finishing of wood and wood based materials: Part 2 Schedules
IS : 2366-1983	Codce of practice for nail-jointed timber construction (*frist revision*)
IS : 2377-1967	Tables for volume of cut-sizes of timber (*first revision*)
IS : 2408-1963	Methods of static tests of timber in structural sizes
IS : 2455-1974	Methods of sampling of model trees and logs for timber testing and their conversion (*first revision*)
IS : 2700-1964	Code of practice for roofing with wooden shingles
IS : 3037-1965	Specification for bitumen mastic for use in water-proofing of roofs
IS : 3337-1978	Specification for ballies for general purpose (*first revision*)
IS : 3364 (Part 1)-1976	Methods of measurement and evaluation of defects in timber: Part 1 Logs (*first revision*)
IS : 3364 (Part 2)-1976	Methods of measurement and evaluation of defects in timber: Part 2 Converted timber (*first revision*)
IS : 3629-1966	Specification for structural timber in building
IS : 3670-1966	Code of practice for construction of timber floors
IS : 3731-1985	Specification for teak squares (*first revision*)
IS : 4020-1967	Methods of tests for wooden flush doors: Type tests
IS : 4021-1983	Specification for timber door, window and ventilator frames (*second revision*)
IS : 4423-1967	Guide for hand-sawing of timber.
IS : 4891-1968	Preferred cut-sizes of structural timbers.
IS : 4895-1985	Specification for teak logs (*first revision*)
IS : 4907-1968	Methods of testing timber connectors.
IS : 4913-1968	Code of practice for selection, installation and maintenance of timber doors and windows.
IS : 4924 (Part 1)-1968	Method of test for nail-jointed timber trusses: Part 1 Destructive test
IS : 4924 (Part 2)-1968	Method of test for nail-jointed timber trusses: Part 2 Proof test
IS : 4962-1968	Specification for wooden side sliding doors
IS : 4970-1973	Key for identification of commercial timbers (*first revision*)

IS : 4983-1968	Code of practice for design and construction of nailed laminated timber beams
IS : 5119 (Part 1)-1968	Code of practice for laying and fixing of sloped roof coverings: Part I slating
IS : 5246-1969	Specification for coniferous logs
IS : 5389-1969	Code of practice for laying of hardwood parquet and wood block floors.
IS : 5390-1984	Code of practice for construction of timber ceiling (*first revision*)
IS : 5966-1970	Specification for non-coniferous timber in converted form for general purposes
IS : 5978-1970	Code of practice for design of wood poles for overhead power and telecommunication lines
IS : 6056-1970	Specification for jointed wood poles for overhead power and telecommunication lines.
IS : 6198-1988	Specification for ledged braced and battened timber door shutters (*first revision*)
IS : 6313 (Part 1)-1981	Code of practice for anti-termite measures in buildings: Part I Constructional measures (*first revision*)
IS : 6313 (Part 2)-1981	Code of practice for anti-termite measures in buildings: Part 2 Pre-constructional chemical treatment measures (*first revision*)
IS : 6313 (Part 3)-1981	Code of practice for anti-termite measures in buildings: Part 3 Treatment for existing buildings (*first revision*)
IS : 6346-1971	Methods of test for timber props for mines
IS : 6534-1971	Guiding principles for grading and inspection of timber
IS : 6711-1972	Code of practice for maintenance of wood poles for overhead power and telecommunication lines
IS : 6874-1973	Methods of test for round bamboos
IS : 7308-1973	Specification for non-coniferous logs
IS : 7315-1974	Guidelines for design, installation and testing of timber seasoning kilns
IS : 7638-1975	Methods of sampling of plywood
IS : 7683-1975	Code of practice for design, fabrication and maintenance of nail-jointed timber posts from small dimensional timber for overhead electric distribution lines for low voltages
IS : 8720-1978	Methods of sampling of timber scantlings from depots and their conversion for testing
IS : 8745-1978	Methods of presentation of data of physical and mechanical properties of timber

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APPENDIX B

(*Clauses* 4.1 *and* 4.3.1)

IMPORTANT INDIAN PUBLICATIONS IN TIMBER ENGINEERING

(Some of these have been referred in the text by appropriate reference).

Research Papers

1) Guha (SRD), Mathur (CM), Gupta (VK) and Sekhar (AC). Insulating boards from rice straw. *Indian Pulp and Paper*. Vol. 19, April 1965.
2) Gupta (RC), Chauhan (BPS), Tandon (RC), Tiwari (MC) and Jain (NC). Studies on glued laminated constructions. Preliminary studies on the effect of preservatives on bending of *Pinus Rexburghii*. *JTDA*. 20(4), 1974.
3) Masani (MJ) and Gupta (RK). Proof test on full sizes nail-jointed timber trusses for residential buildings (Part II). *IFL*. 183. 1963.
4) Masani (NJ). Economics of timber structures with reference to roof trusses, *IFL*. 169. 1964.
5) Masani (NJ), Pruthi (KS) and Agarwal (SK). Bolted joints for timber structures (bolt bearing strength of wood parallel to grain) (Part I). *IFL*. 180. 1964.

6) Masani (NJ) and Gupta (RK). Mechanically laminated timber construction: Test results and recommendations on design of mechanically laminated beams. *IFL*. 186. 1966.

7) Masani (NJ) and Pruthi (KS). A study of effective lever arm in spliced nail-jointed beams (lengthening (joints, their efficiency and economy) (Part I). *IFL*. 184. 1966.

8) Masani (NJ), Gupta (RK), Bahuguna (JP) and Bachan Singh. Theory and practice of solid web-type nail-jointed timber girder T.E. Manual (Part II). *FRI*. 123. (*revised*). 1966.

9) Masani (NJ) and Pruthi (KS). A note on comparative strength of wood disc dowel joints with different joints in timber framed structures. *IFL*. 185. 1967.

10) Masani (NJ) and Gupta (RK). Test results and recommendations on strength of nail-jointed timber roof trusses for residential buildings (Part I). *IFL*. 182. 1961.

11) Masani (NJ), Gupta (RK) and Bachan Singh. Overhead electric distribution posts from small dimensioned timbers. *IFL*. 192. 1972.

12) Masani (NJ) and Pruthi (KS). Overhead electric distribution posts from small dimensioned timbers. IFL. 192. 1972.

13) Masani (NJ) and Bajaj (AN). Timber resources in India and their utility for structural purposes with emphasis on quality construction and cost of secondary species. Paper presented at the Seminar on Quality Construction and Cost Aspects of Building Timber and Timber Structures, Dehra Dun. 1972.

14) Masani (NJ) and Pruthi (KS). Effects of grain alignments of wooden disc dowels made from radial and tangential plains on the strength of structural joints. 1974.

15) Masani (NJ) and Bajaj (AN). Theory and practice of three hinged arch nail-jointed timber truss. T.E. Manual (Part I). FRI. 101.

16) Masani (NJ) and Pruthi (KS). Some fundamental aspects regarding lateral strength of ordinary wire nails used as connectors in timber construction. IFL, Vol. I.

17) Narayanamurti (D) and Bist (BS). Building boards from bamboos. IFR, Vol. I. No. 2. CW Branch, Forest Research Institute, Dehra Dun. 1963.

18) Purushotham (A). Low cost structures. *TDPA J*. 9 (3), 2-26, 1963.

19) Purushotham (A), Pande (JN) and Sood (JS). A note on fire-resistive-*cum*-antiseptic composition and fire resistive paint. *TDPA J*. 9 (3), 27-28, 1963.

20) Purushotham (A). Instructions for treatment of timber bamboo, etc, where facilities for treatment are not available. *JTDA*. 9 (4). 1963.

21) Purushotham (A). Fire resistive compressed thatch boards. *JTDA*. 12 (4). 1966.

22) Rehman (MA), Ghosh (DP) and Mehra (ML). Design and operation of an improved type of indirect-heat thermal circulation furnaces kiln. IFB. 226. WS Branch, Forest Research Institute, Dehra Dun. 1966.

23) Sekhar (AC) and Rana (RS). Nail and screw holding power of Indian timbers. *IFR* (TM). 5, 1956.

24) Sekhar (AC). Notes on grading of timbers in India. *Soc. Ind. Fores.* II (1) 1962.

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29) Sekhar (AC) and Tarlok Singh. A note on a survey of timber structure in India. Paper presented at the Symposium on Timber and Allied Products. NBO New Delhi. 1959.

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32) Sekhar (AC). Structural utilization of wood in India, *J. Soc. Ind. Forest*. IV, (1), 1964.

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APPENDIX C

(*Clause* 2.4.2)

A DICHOTOMOUS KEY FOR THE IDENTIFICATION OF 25 COMMERCIAL TIMBERS OF INDIA

1 a)	Wood non-porous	2
b)	Wood porous	7
2 a)	Resin canals absent	3
b)	Resin canals present	4
3 a)	Wood without any odour, white and very soft, no colour distinction between sapwood and heartwood, fir (*Abies pindrow*)	

	b)	Wood with pungent odour, light yellowish-brown, moderately hard, sapwood and heartwood distinct, deodar (*Cedrus deodar*)	
4	a)	Resin canals scattered	5
	b)	Resin canals in long, tangential bands wood with pungent odour	Deodar (*Cedrus deodara*)
5	a)	Resin canals minute appearing as white dots, visible only under the lens, wood without any odour	Spruce (*Picea smithiana*)
	b)	Resin canals large, distinctly visible to the eye, wood with strong resinous odour	6
6	a)	Transition from early wood to late wood abrupt, wood yellowish to pale reddish-brown, moderately hard, medium coarse-textured	Chir (*Pinus rexburghii*)
	b)	Transition from early wood to late wood gradual, wood light pinkish-red to light red, rather soft, fine-textured	Kail (*Pinus wallichiana*)
7	a)	Wood ring-porous to semi-ring-porpous	8
	b)	Wood diffuse-porous	12
8	a)	Early wood pore-zone broad changing abruptly to late wood, extreme late wood pores in clusters often arranged in zigzag fashion, wood golden yellow turning brown on exposure	Mulberry (*Morus alba*)
	b)	Early wood pore-zone narrow, showing gradual transition to late wood, late wood pores mostly solitary or in short radial multiples	9
9	a)	Parenchyma round the pores abundant and conspicuous, predominantly aliform to confluent, often forming numerous wavy bands	10
	b)	Parenchyma round the pores scanty and inconspicuous, mostly vasicentric	11
10	a)	Ripple marks present, wood yellowish brown to golden brown with yellow water extract giving strong fluorescence	Bijasal (*Pterocarpus marsupium*)
	b)	Ripple marks absent, wood usually greyish to light reddish or walnut-brown, water extract of wood without any fluorescence	Benteak (*Lagerstroemia lanceolata*)
11	a)	Wood pinkish or reddish-brown with cedary smell, rather lustrous, pores often filled with dark reddish-brown gummy deposits	Toon (*Toona ciliata*)
	b)	Wood golden-brown with characteristic smell of old leather, dull, pores partly filled with tyloses	Teak (*Tectona grandis*)
12	a)	Vertical gum ducts present	13
	b)	Vertical gum ducts absent	14
13	a)	Gum ducts scattered singly or in short tangential groups of 2-4, sometimes more, pores partly filled with tyloses	Gurjan (*Dipterocarpus*)
	b)	Gum ducts in long tangential lines, pores heavily plugged with tyloses	Sal (*Shorea robusta*)
14	a)	Ripple marks present	15
	b)	Ripple marks absent	18
15	a)	Soft tissues predominantly banded, water extract of wood with characteristic fluorescence	Bijasal (*Pterocarpus marsupium*)
	b)	Soft tissues prodominantly aliform confluent, water extract of wood without any fluorescence	16

16	a)	Wood light yellow or yellowish grey, pores often filled with white chalky deposits	Kanju (*Holoptelea integrifolia*)
	b)	Wood golden brown or purplish-brown, pores often filled with gummy deposits	17
17	a)	Wood golden brown with darker streaks and without any sweet smell	Sissoo (*Dalbergia sissoo*)
	b)	Wood purpish brown to deep purple with sweet smell	Rosewood (*Dalbergia latifolia*)
18	a)	Pores in long radial chains or oblique groups	19
	b)	Pores not in long radial or oblique groups	20
19	a)	Soft tissues in diffuse-in-aggregates or fine lines	Pali (*Palaquium ellipticum*)
	b)	Soft tissues in narrow concentric bands ending abruptly	Poon (*Calophyllum* sp.)
20	a)	Pores small, visible only under the lens	21
	b)	Pores mostly medium-sized to large or very large, visible to the eye	23
21	a)	Growth rings delimited by distinct band or a line of parenchyma	Champ (*Michelia champaca*)
	b)	Growth rings not delimited by a band of parenchyma	22
22	a)	Parenchyma paratracheal, forming thin sheaths or euelets round the pores, often confluent connecting adjacent pores, wood olive grey or pale yellowish-brown, hard	Axewood (*Anogeissus latifolia*)
	b)	Parenchyma apotracheal, rather inconspicuous under the lens, mostly diffuse, wood yellowish, moderately hard	Haldu (*Adina cordifolia*)
23	a)	Rays broad distinctly visible to the eye conspicuous under the lens	24
	b)	Rays fine, distinct only under the lens	25
24	a)	Soft tissues round the pores vasicentric wood hard, heavy light reddish-brown	Babul (*Acacia nilotica*)
	b)	Soft tissues in fine, closely spaced, somewhat broken tangential lines forming reticulam, wood light, creamy white to pale yellow or buff	Semul (*Bombax ceiba*)
25	a)	Parenchyma round the pores mostly vasicentric to aliform	26
	b)	Parenchyma round to pores predominantly confluent	28
26	a)	Wood usually dark coloured, usually yellowish white or pinkish-brown	Mango (*Mangifera indica*)
	b)	Wood usually dark coloured, usually a dark shade of brown often with dark streaks.	27
27	a)	Initial or terminal parenchyma always present prominent under the lens forming a continuous line delimiting growth rings	Laurel (*Terminalia tomentosa*)
	b)	Initial or terminal parenchyma absent, if present, discontinuous and inconspicuous even under hand lens	Kokko (*Albizia lebbeck*)
28.		Wood golden brown with darker streaks and without any sweet smell	Sissoo (*Dalbergia sissoo*)
29.		Wood purplish brown to deep purple with sweet smell	Rosewood (*Dalbergia latifolia*)

APPENDIX D

(*Clause* 3.1.1)

D-1 SUMMARY OF SCHEME OF TESTS ON SMALL CLEAR SPECIMENS OF TIMBER

Sl No.	*Mechanical Test*	*Size of Specimen in mm*	*Speed of Testing*	*Surface on which Load is Applied*	*Properties Determined*
(1)	(2)	(3)	(4)	(5)	(6)
i)	Static bending	50 × 50 × 750 on span of 700 mm	Movable head travels at 2.5 mm/min	Tangential surface nearer to the heart	FS at LP; M of R; M. of E; work to EL; work-to Max load; total work; HS at PL; HS at ML
ii)	Impact bending	do	Increment in steps of 25 mm up to 250 mm and 50 mm beyond 250 mm, until complete failure or deflection of 150 mm is reached	do	FS at LP; M of E; work to EL; Max. height of drop; height of drop at limit of proportionality
iii)	Compression parallel to grain	50 × 50 × 200 on a gauge length of 150 mm	Movable head travels 0.6 mm/min	Cross-section	CS at LP; CS at ML; M of E in compression parallel to grain
iv)	Compression perpendicular to grain	50 × 50 × 150	Movable head travels 0.6 mm/min	Radial surface	CS at LP; compressive stress at compression of 2.5 mm; CS at ML; M of E in compsersion perpendicular

F.S. = Fibre stress; L.P. = Limit of proportionality; M of R = Modulus of rupture; M of E = Modulus of elasticity; H.S. = Horizontal shear; C.S. = Crushing stress; M.L. = Maximum load; E.L. = Elastic limit.

Sl No.	*Mechanical Test*	*Size of Specimen in mm*	*Speed of Testing*	*Surface on which Load is Applied*	*Properties Determined*
(1)	(2)	(3)	(4)	(5)	(6)
v)	Indentation test (hardness)	50 × 50 × 150	Movable head travels 6 mm/min	Two penetrations on radial, two on tangential surface and one on each end	Max. load to embed a steel ball of 11.3 mm dia to half its dia
vi)	Shear	50 × 50 × 62.5 with a corner notch to produce failure on 50 × 50 mm surface	0.4 mm/min	One for radial and one for tangential	MSS maximum load/shearing area
vii)	Tension perpendicular to grain	50 × 50 × 56 with semi-circular group for gripping so as to produce a failure on a 50 × 20 mm area in the radial or tangential plane	Movable head travels at a constant rate of 2.5 mm/min until *max* load is reached	One for radial and one for tangential	Max load/tension area
viii)	Tension parallel on grain.	7 × 7 mm cross-section, 50 mm gauge length, and wide surface for gripping	Movable head travels 1 mm/min	Cross-section	TS at PL; TS at ML; and M of E in tension
ix)	Torsion	Cylindrical specimen of 25 mm diameter gauge length 15 mm suitable grips	Torque is applied at the uniform rate of 600 cm. kg/min	Cross-sectional rotation	Torsional shear stress at proportional limit (TSS at PL), torsional shear stress at max torque (TSS at MT) and torsional modulus of rigidity

T.S. = Tensile stress; P.L. = Same as L.P = Limit of proportionality; M.L. = Maximum load.

Sl No.	Mechanical Test	Size of Specimen in mm	Speed of Testing	Surface on which Load is Applied	Properties Determined
(1)	(2)	(3)	(4)	(5)	(6)
x)	Nail and screw pulling test	50 × 50 × 150	Movable head travels at the speed of 2mm/min	One nail and one screw on each of radial and tangential surfaces and one each on end surfaces	Maximum withdrawal load under three conditions: (a) nails and screws driven in green condition and pulled out at once, (b) driven in green and pulled in dry condition, and (c) driven in dry and pulled in dry condition
xi)	Brittleness test.	(a) Load test 20 × 22 × 125 to 150 mm with key-note (b) Charpy test 12.5 × 12.5 × 125 mm with notch	The impact blow shall be given by releasing the pendulum and allowing the same to fall freely	22 × 12 mm cross-section at a distance 75 mm from one end on the tangential side of load test and 10 × 12.5 mm at the centre on the reverse side in case of Charpy test	Energy absorbed in breaking the specimen on a single below, expressed in units of cm.kg

D-2 FORMULAE BASED ON IS : 1708-1969

Some important formulae for deriving ultimate stresses in various tests on small clear specimen, *see* **3.1.1**. For other properties derived as a routine *see* IS : 1708-1969.

Property	*Units*	*Formula*
a) *Static Bending*		
1) Fibre stress at limit of proportionality	kg/cm^2	$\frac{3pl}{2bh^2}$
2) Equivalent fibre stress at maximum load	kg/cm^2	$\frac{3p^1l}{2bh^2}$
3) Modulus of elasticity in static bending	1000 kg/cm^2 or metric tonnes per cm^2	$\frac{pl^3}{4\Delta bh^3} \times \frac{1}{1\,000}$
4) Horizontal shear stress at maximum load	kg/cm^2	$\frac{3}{4}\,\frac{p^1}{bh}$
b) *Impact Bending*		
1) Fibre stress at limit of proportionality	kg/cm^2	$\frac{3WHl}{bh^2\Delta}$
2) Maximum height of drop	cm	H^1
3) Modulus of elasticity in impact bending	1000 kg/cm^2 or tonnes/cm^2	$\frac{WHl^3}{2bh^3\Delta^2} \times \frac{1}{1\,000}$
c) *Compression Parallel and Perpendicular to Grain Tension and Shear Tests*		
1) Compressive or tensile stress at limit of proportionality	kg/cm^2	$\frac{P}{A}$
2) Compressive stress or tensile stress at maximum load (or at 2.5 mm compression in the case of compression perpendecular to grain if the same in reached before maximum load)	kg/cm^2	$\frac{p^1}{A}$
3) Modulus of elasticity in compression (parallel or perpendicular as the case may be)	1000 kg/cm^2 or tonnes/cm^2	$\frac{Pl(\text{or } h)}{\Delta A} \times \frac{1}{1\,000}$
4) Maximum shear stress	kg/cm^2	$\frac{\text{Max. load}}{\text{Area of shear failure}}$

In the above formulae, the notations are as follows:

l = span of the test specimen in cm in bending or guage length in compression and tension tests;

b = breadth of the specimen in cm (sometimes known as width);

h = depth of the specimen in cm (or sometimes known as height);

p = load in kg at limit of proportionality (commonly known as elastic limit);

p^1 = maximum load in kg (in the case of compression perpendicular to grain the load at 2.5 mm if the same is reached before the maximum load);

Δ = total deflection at the limit of proportionality in bending or total compression in compression tests or elongation in tension tests;

H = height of drop of hammer at a limit of proportionality in the impact bending test on a Hatt-Turner machine, and

A = area in cm^2 of the section of the specimen on which load is applied.

APPENDIX E

(*Clause* 3.1.2)

SUMMARY OF SCHEME OF TESTS ON STRUCTURAL SIZES OF TIMBER BASED ON IS : 2408-1963

For more detailed description of procedures for layout and general precautions to be taken, reference should be made to IS : 2408-1963. The following is only a summary of some important considerations in the tests.

a) Measurement of dimensions are to be correct to the nearest millimetre.

b) Weights of the specimens are to be taken to an accuracy of 0.1 kg.

c) The origin of the test piece, and all defects on the specimen are to be accurately recorded.

d) The failure of the specimen is carefully sketched out for analysis, and the average moisture content of the piece, preferably near the areas of failure, are determined as usual by the even-dry method. Average moisture content of all zones of cross-sectional area are to be determined as described in IS : 2408-1963.

e) The detail of static bending test are as given below:

1) *Size* : 15 × 20 × 350 cm

2) *Span of test* : 14 times the height of specimen

3) *Loading* : At two points at a distance of one-third of the span. Load is applied continuously with a uniform motion of moveable head at a speed

$$N = \frac{Za}{3h}(3L - 4a) = 3.5\ Z \times L$$

for the above

4) *Deflection* : measured at mid-span, mid-height at convenient load intervals say, 2 000 kg.

5) *Formulae* :

Maximum horizontal shear, that is, at maximum load

$$= \frac{3p}{4bh}\ \text{kg/cm}^2$$

Modulus of rapture (M of R)

$$= \frac{(p + 0.75w)L}{bh^2}\ \text{kg/cm}^2$$

Fibre stress at limit of proportionality

$$= \frac{(p^1 + 0.75w)L}{bh^2}\ \text{kg/cm}^2$$

Modulus of elasticity (M of E)

$$= \frac{p^1 L^3}{4.7\Delta bh^3}\ \text{kg/cm}^2$$

f) Compression perpendicular to grain

1) *Size* : 15 × 20 × 70 cm.

2) *Loading* : on the entire width of the specimen at its centre through a thick metal plate of 15 cm width and 1 cm thick under uniform motion of moveable head speed calculated by the formula $N = 0.0291\ p^{4/9}$

3) *Compression readings* : correct to 0.002 cm at suitable load intervals until 1/5 of the depth of the specimen or failure whichever is reached earlier.

4) *Formulae* :

Crushing strength at maximum load, if any (CS at ML) or as above

$$= \frac{P}{A}\ \text{kg/cm}^2$$

Crushing stress at limit of proportionality (CS at LP)

$$= \frac{P^1}{A}\ \text{kg/cm}^2$$

g) Compression parallel to grain:

1) *Size* : 15 × 15 × 60 cm

2) *Loading* : on the entire cross-section, vertically at a uniform speed given by $N = ZL$

3) *Compression readings* : Correct to 0.002 over a centre guage length of ¼ of the length of the specimen until the specimen fails.

4) *Formulae* :

Compressive strength at maximum load (CS at ML)

$$= \frac{P}{A}\ \text{kg/cm}^2$$

Compressive stress at limit of proportionality

$$= \frac{P^1}{A} \text{ kg/cm}^2$$

Modulus of elasticity in compression parallel to grain

$$= \frac{P^1}{A} - \frac{d^1}{\Delta} \text{ kg/cm}^2$$

where

N = head speed in cm per minute,

Z = unit rate of strain of outer film ($Z = 0.0007$ for large beams and equal to 0.0015 for compression,

a = distance from support to nearest load in cm,

P = maximum load in kg,

p^1 = load at limit of proportionality (elastic limit) in kg,

b = width of the specimen in cm,

h = height of the specimen in cm (or also known as depth),

L = length of the span in bending and length of the specimen in compression parallel to grain,

d^1 = distance between guage points in compression parallel to grain in cm,

w = weight of the specimen in kg,

A = area or cross-section of specimen (cm^2) under load, and

Δ = deflection (in bending) or compression in compression test at limit of proportionality.

APPENDIX F

(*Clause* 6.1.1)

LIST OF TIMBER DESIGNS DEVELOPED AT THE FOREST RESEARCH INSTITUTE, DEHRADUN

(Some of these would be available with Forest Research Institute and some have been published in different publication)

1. Nail jointed roof trusses for residential buildings (3 to 6 metres in light, medium and heavy weight roofing material)
2. Nail-jointed roof trusses for industrial sheds (7 to 16 metres, in light medium and heavy weight roofing material)
3. Bolt-jointed timber trusses (3 to 8 metres in light, medium and heavy weight roofing material)
4. Cantilever timber trusses (3 to 6 metres in light, medium and heavy weight roofing material)
5. Dowel jointed trusses for chemical shed (14 metres in medium weight roofing material)
6. Three-hinged arch timber trusses (7 to 24 metres in light and medium weight roofing material)
7. Timber lamella arches (6 to 19 metres in light and heavy weight roofing material)
8. Solid web type timber girders and purlins (3 to 6 metres in light and medium weight roofing material)
9. North light timber trusses (8 to 12 metres for medium weight roofing material)
10. Leanto-type trusses (6 to 10 metres in light, medium and heavy weight roofing material)
11. Aeroplane type trusses (4 and 12 metres for light and heavy weight roofing material)
12. Bow string type arch trusses (20 and 30 metres for light weight roofing material)
13. Timber bridges (3 to 18 metres for Class B loading)
14. Electric transmission posts in timber (6.25 and 9.25 metres high for low voltage line)
15. Grain silos and storage sheds:
    a) Storage shed in timber (100, 300 and 1 000 M.T. capacity)
    b) Grain silo in timber (2.5, 5 and 20 M.T. capacity)
    c) Grain silo using bamboo reinforced cement concrete (2.5 and 5 M.T. capacity)
16. Anti-termite-*cum*-damp-proof constructional gadgets.
17. Type designs and drawings of typical buildings:
    a) Residential houses for types I, II, III and IV
    b) Various types of farm houses in timber

c) Model houses for different regions

d) Tree-top tourist huts in timber

e) Mini bus stands in timber

f) Storage godowns for different capacities

g) Chowkidar-*cum*-check post hut in bamboo-concrete roof

h) Deer park shed

j) Two ways bus stoppage shed

k) Sports pavilions

m) Hostel blocks

n) Children park sheds

p) Forest rest houses

q) Tourist huts in timber

r) Tourist bunglows

s) Workshop buildings

t) Assembly halls

u) Cheap poultry houses

w) Community halls

x) Cycle, car and scooter sheds

y) Airport buildings, etc

APPENDIX G

(*Clauses* 2.3.3, 2.3.6.3, 2.3.7, 5.2.5.3 *and* 5.2.6.2)

STRUCTURAL SPECIES OF DIFFERENT GROUPS, THEIR TRADE NAMES, OTHER INDIAN NAMES, AVAILABILITY, DURABILITY, TREATABILITY AND REFRACTORINESS

Sl No.	*Botanical Name*	*Locations where Grown*	*Standard Trade Name* (IS : 1150)	*Names in some other Languages*	*Approximate Quantity Available per Year*	*Durability*	*Treatability*	*Refractoriness*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GROUP A								
1.	*Acacia catechu*	UP, Bihar, Gujarat, Karnatka and Maharashtra	Khair	Khaira (As) Khaih (O) Kath (K)	U	I	—	H
2.	*Acacia chundra*	MP	Red kutch Lal khair	—	—	—	—	H
3.	*Agalai edulis* and other spp.	Assam	Agalai	Latakh (As) Kanangal (Ml) Chokkala (Tm)	—	—	—	H
4.	*Albizzia odorarissima*	MP, Assam, TN, Maharashtra, UP, Orissa, Nagaland, Kerala, Gujarat, Karnataka and Arunachal Pradesh	Kalasiris	Hilanid (As) karoi (B) Karumuru (p) Srisi (Mr) Chictwa (MP) Kaloisiras (G) Bilkambi, Godtunchi (K) Eldavagai (K) Kasubaka (Ml) Karuvagai (Tm) Chindugu (Tl)	V	I	e	M
5.	*Balanocarpus utilis (Hopea utilis)*	TN	Karung	Karun (Tm) Kongu	—	—	—	—
6.	*Bruguiera* spp.	Andaman	Mangrove		—	—	—	—
7	*Cynometra polyandra (Mamitoa Polyandra)*	Assam	Ping (As)		W	III	b	H

(*Continued*)

Sl No.	Botanical Name	Locations where Grown	Standard Trade Name (IS : 1150)	Names in some other Languages	Approximate Quantity Available per Year	Durability	Treatability	Refractoriness
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
8.	*Dipterocarpus macrocarpus*	Assam and Arunachal Pradesh	Hollong (As)	—	V	III	a	M
9.	*Eucalyptus globulus*	South India	Eucalyptus	Karpooramaram (Tm)	—	I	e	H
10.	*Grewia tiliaefolia*	South India	Dhaman	Phalsa (p) (MP) Gonya (Kol) Dedsal, Thadsal (K) Chdachi (MR) Thadachı (Tm) Peddajana (Tl)	V	II	d	M
11.	*Hopea glabra* (and other species except *H. odorata*)	West Bengal, Karnataka, Nagaland, Arunachal Pradesh, Kerala and TN	Hopea	Kiralobigi (K) Kalhori (Mr) Bogina (K) Irumbogam (Ml) Vellaigonge (Tm)	—	—	—	—
12.	*Hopea parviflora*	South India	Hopea	do	W	I	e	H
13.	*Messua ferrea*	Assam, Andamans and TN	Messua	Nagasampigi (K) Churuli (Ml) Nangal, Nangu (Tm) Nagakesari (Tl) Gangana (And) Nahor (As) Nageswar, Nagkesar, (B) Nagwar (O)	—	I	e	H
14.	*Mimusops littoralis* (*Manilkara littoralia*) (and other sp.)	Andamans	Bulletwood	Khirni (MP) Borsali-Rajan (G) Mugali (K) Elingi (Ml) Ranjana Wovali (Mr) Bakula (K) Nampala (Tm) Pala (Tl)	W	I	—	H
15.	*Poeciloneuron indicum*	TN, Karnataka, and Kerala	Ballagi	Balige, Balagi (K) Vayal (Ml) Puttangali (Tm)	—	II	e	H
16.	*Pterocarpus santalinus*	TN and AP	Red sanders	Raktachandanam (K) (Ml) Yerrasandanam (Tl) Chemmaram (Tm)	W	—	—	—

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
17.	*Sageraea elliptica*	South Andamans	Chooi	—	—	—	—	H
18.	*Schleichera trijuga* (*Scheichera eleosa*)	MP, Bihar, Orissa, UP, Kerala and Karnataka	Kusum	Beru (Kol) Kusuma (O) Sagada Sagodi (K) Hosimlim Kusumb (Mm) Puvam (Ml) (Tm) Pulusari (Tl)	V	III	a	H
19.	*Shorea robusta*	Bihar, MP, Assam, WB, Orissa and UP	Sal	Sakhma (Him) Sangam (Kol) Raigabu, Sangi (O)	U	I	e	H
20.	*Shorea talura*	—	—	—	W	—	—	—
21.	*Vitex altissima* (and other spp.	Maharashtra, TN, Kerala and Karnataka	Milla	Naviladi, Nevaladi, Nevole, (K) Myladi (Ml) (Tm) Nagod (G) Nemiliyadugu (Tl)	—	I	—	H
GROUP B								
22.	*Acacia arabica* (*Acacia nileti-ca*)	MP, UP, TN, AP, Bihar and Karnataka	Babul (H) (M.)	Kikkar (P) Babla (B) Baval (G) Fali, Jali, Mashwel, Kanjali (K) Karuvelam (Ml) Karuvai (Tm) Nallatunma (Tl)	U	III	b	M
23.	*Acacia kerruginea*	—	—	—	—	—	—	—
24.	*Acrocarpus fraxini-folius*	Karnataka, MP, WB and Nagaland	Mundani	Mundane (N) Belanji (K) Kuranyam, Malareppu (Ml) Malamkomnai (Tm)	W	III	c	M
25.	*Albizia lebbeck*	Adaman, WB, Maharashtra, MP, Assam, TN, AP, Kerala and Karnataka	Kokko	Siris (H) (O) Sarin, Shrin (P) Hirih (As) Sirish (B) Chichola, Sirias (Mr) Baka (Ml) Sirsul, Bage (K) Vagai (Tm) Dirisinum (Tl)	V	I	c	M

(Continued)

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
26.	*Altingia excelsa*	Assam, Arunachal Pradesh, TN, MP and Maharashtra	Jutili (As)	—	W	II	e	H
27.	*Amoora rohituka* (Aphanamix is polystachya)	Assam	Pitraj	Bogaamali (As) Lochumi (B) salvagai (K) Raktarohida (Mr) Bellabakka (Ml) Velragai (Tm) Tellachinduga (Tl)	W	I	—	M
28.	*Anogeissus acuminata*	Orissa	Yon	Garalessal (Kol) Phansi (O)	—	I	c	H
29.	*Anogeissus latifolia*	UP, MP, AP, TN, Bihar, Orissa and Maharashtra	Dhaura (H) (axlewood)	Bakli (H) Chal (HP) Dhao (P) Hessel (Kol) Banghi (N) Bhaw (O) Dividal Dinduga, Begjal (K) Bellanava (Ml) Vellanagai (Tm) Chirumanu (Tl) Bhavdo, Bhavro (Mr) (G)	—	I	c	H
30.	*Anogeissus endula*	—	Kardhai	Dhao, Ratdahi (H) Kardahi (MP)	—	III	—	H
31.	*Artocarpus hirsutus*	TN, Karnataka and Maharashtra	Aini	Hobulsina, Hebbalusu (K) Ainipilavu (Ml) Anjali, Ainipila (Tm) Patupanas (Mr) Junglinimb (H)	—	III	—	H
32.	*Atlantia monophylla*	—	—	—	—	—	—	—
33.	*Bassia butyracea*) (*Diploknema butyracea*) (Madhuk sp.)	Andaman and UP	Hill mahua or mahua	Mahuda (G) Mohwa (Mr) Ippa (Tl) Ippi, Sannaippe (K) Nattuillupai (Tm)	—	—	—	—
34.	*Buchlandia* (*Exbuchlandia*) *populnea*	—	Pipli (B)	—	—	—	—	—

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
35.	*Callophyllum tementosum* and spp.	TN, WB, Karnataka and Maharashtra	Poona	Sushoni, Goja, Salhonne (K) Punna (Mr) Kathupinnai (Tm)	—	II	e	M
36.	*Canarium strictum* and sp.	TN and Maharashtra	Dhup or white dhup	Raldhup (K) Gugul (Mr) Kunthinikka, Payin (Ml) Karumkungiliam, Karapu (Tm)	—	III	—	L
37.	*Carallia lucida* (*carallia brachiata*)	Assam, Bihar and Gujarat	Maniawga or carallia	—	—	—	—	—
38.	*Carapa moluccensis* (*xylocarpus, moluccensis*) and sp.	—	Pussar	—	—	—	—	—
39.	*Cassia fistula*	—	Am and altas	Kaniyar (P) Sanaru (As) Bandarlatti (B) Hani (Kol) Sonalu (N) Mahalimbo (O) Bahaiyar, Bhava (Mr) Gurmala Gumalo (G) Kakke (K)	—	II	—	H
40.	*Cassia siamea*		—	—	—	—	—	—
41.	*Casurina equisetifolia*	TN, Maharashtra, Kerala, Karnataka, Gujarat and Nagaland	Casuarina	Jhaw (B) Jhawn (O) Saru (G) (Mr) Savaku (Tm) Galimaru, Kasarika (K) Saru (Mr) Chulamaram (Mr) Saravu, Chavaku (Tl)	V	III	c	H
42.	*Chloroxylon swietenia*	—	Satinwood	Bherul (H) Bheru (O) Ghiria (Bhopal) Behra, Bhirra (Mr) (MP) Billa (Mr) Muragalu, Mashwal (K) Porasu (Tm) Bilga, Billa (Tl)	—	III	—	H

(*Continued*)

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
43.	*Chukrasia tabularis* (*Chukrasia velutina*)	Assam, Karnataka, Arunachal Pradesh and Nagaland	Chikrassy	Yinmabin (And) Bogopoma (As) Urulu (K) Malaveppa (Ml) Madagirivembu (Tm) Laldevdari (Mr)	W	III	c	M
44.	*Cullenia rosayroana* (*Cullenia excelsa*)	TN and Kerala	Karani	Mullachekka (Ml) Ainipila, Vedipila (Tm)	W	III	b	L
45.	*Dichopsis elliptica* (*Pallaquiem ellipticum*	Assam and South India	Pali	Hadasale (K) Palvadinjan (Tm)	W	II	e	M
46.	*Dichopsis* (*Palaquium Ass.*) *Polyantha* (*Polyanthum*)	—	Tali	Hadasale (K) Palvadinjan (Tm)	W	—	—	—
47.	*Diospyros microphylla* and sp. except *D. marmorata*	—	Ebony	Tupra (K) Thumbi (Tm) Tukki, Tumiki (Tl)	—	III	—	M
48.	*Diospyris pyrrhocarpa*	—	Ebony	Tupra (K) Thumbi (Tm) Tukki, Tumiki (Tl)	—	—	—	—
49.	*Dipterocarpus bourdilloni*	Andaman	Gurjan	Garjan (As)	—	—	—	—
50.	*Dipterocarpus grandiflorus* and sp. except *D. macrocarpus*	W.B., Assam, TN and Karnataka	Gurjan	Garjan (As)	—	III	b	M
51.	*Dipterocarpus indicus*	—	Gurjan	Garjan (As)	—	—	—	—

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
52.	*Dysoxylum malabaricum*	Kerala, Arunachal Pradesh, TN and Karnataka	White cedar	Bilidevdari (K) Vellagil (Ml) (Tm)	W	I	—	M
53.	*Eucalyptus eugenoides*	TN	Eucalyptus	—	W	—	—	—
54.	*Eugenia* sp. (*gardneri*) *Syzygium* sp.	UP	Jaman	Jamun (H) Jamuk (As) Jam (B) Kude (Kol) Jamu (O) Jambu (G) Nerlu (K) Jambul (Mr) Jamun (MP) Neral (Tm) Neredu (Tl)	U	II	e	H
55.	*Eugenia jambolana* (*Syzygium cumini*)	UP, WB, Assam, Orissa, Nagaland, Karnataka, Bihar, Kerala and Arunachal Pradesh	Jaman	Jamun (H) Jamuk (As) Jam (B) Kude (Kol) Kamu (o) Jambu (G) Nerlu (K) Jambul (Mr) Jamun (MP) Nerak (Tm) (Ml) Neredu (Tl)	U	—	—	—
56.	*Fraxinus excelsior* and sp.	HP and UP	Ash	Hum (Kashi) Sum (p)	—	III	—	M
57.	*Eraxinus macrantha*	HP and UP	Ash	—	—	—	—	—
58.	*Garuga pinnata*	UP, MP, TN, and Maharashtra	Garuca	Ghoghar, Kaikar, Karapat (H) Kharpat (O) Armu (Kol) Kathkusum, Rajmoir (O) Kakad (Mr) Ghoghar (MP) Kakad Karapti (G) Kurak, Holabolagi, Godda (K) Amakera (Ml) Kanuvembu (Tm)	—	III	e	M
59.	*Gluta travancorica*	Kerala and TN	Gluta	Devdari (K) Chenkaranchi (Ml) Senkuranji (Tm)	W	I	—	H
60.	*Grewia vestita* (*Grewia tilifolia*)	Maharashtra, TN, UP, MP, Orissa, Kerala and Karnataka	Dhaman	Phalsa (P) (Mp) Gonyar (Kol) Dadsal Tadsal (G) (K) Chadachi (Ml) Thadachi (Tm) Peddejana (Tl)	V	II	d	M

(Continued)

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
61.	*Hardwickia pinnata* (*Kingiodendron pinantum*)	TN, AP and Karnataka	Piney	Yennamaru (K) Chukanapayini (Ml) Kolavu (Tm)	W	I	e	M
62.	*Heritiera* spp.	—	Sundri	—	—	—	—	—
63.	*Kavea floribunda* (*Messua floribunda*)	Assam	Karal	—	—	—	—	—
64.	*Lagerstroemia lanceolata*	UP, Maharashtra, Karnataka, Kerala and Nagaland	Benteak	Nana (G) (Mr) Nandi (K) Bendekku (K) Venteak (Ml) Bethekku, Venthekku (Tm)	V	I	e	M
65.	*Lagerstroemia parviflora*	—	Lendi	Bondam (G) Asidh, Dhauri, Sida (H) Machi (As) Sidha (B) (O) Garasekre (Kol) Bundhameru (N) Lendiasenha (Mr) Kehisaja, Lendia (MP) Chennangi (K) (Tl) Nanagu (Ml) Peikudukkai (Tm)	—	III	e	H
66.	*Machilus odoratissima* and spp.	WB and Arunachal Pradesh	Machilus	Kawala (N) Gulmaru, Gulum, Gulmao (K) Poswa (Mr) Unavu (Ml) Kolumavu (Tm)	—	I	—	L
67.	*Mimusops ellingi* (*Manilkera* sp.)		Bulletwood (bakul)	Khirni (MP) Borsali, Rayan (G) Mugali, Bakula (K) Ranjana, Wovali, (Mr) Elingi (Ml) Nanupala (T) Pala (Tl)	W	—	—	—
68.	*Palaquium ellipticum* (*Dichopsos ellipticum*)	Assam	Pali tali	Hadasule (K) Palvadinjan (Tm)	—	—	—	—

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
69.	*Planchonia addamanica valida*		Red Bombway	—	—	III	—	—
70.	*Pterocarpus dalbergiodes*		Padhuk	—	V	I	c	M
71.	*Pterocarpus marsupium*	MP, AP, TN, UP, Gujarat, Bihar and Karnataka	Bijasal	Pigasal (B) (O) Hid (Kol) Bija (MP) Beo (G) Nonna (K) Bibla (Mr) Venga (Ml) Vengai (Tm) Yegi (Tl)	U	I	c	M
72.	*Quercus*	Punjab, UP, Assam, J & K and WB	Oak	Balk (B) Phalant (N) Mohru, Moru (H) Tilanj, Phanant (H) Bami (P) Ban, Bhani, Rianj, (H) Kharasu (H)	W	II	—	H
73.	*Saecopetalum tomentosum* (*Miliusa tomentoseum*	—	Hoom	Humb (G) (Mr) Womb (K)	—	III	—	M
74.	*Soyameda febrifuga*	UP, Karnataka and Gujarat	Rohini (Indian redwood)	Rohina (B) Rohan (H) Rohini (Kol) (O) Sohan, Swan (O)	W	—	—	—
75.	*Sterculia alata* (*Pterygota alata*)	—	Narikei	Labkoh (And) Pahari (As) Tula (B) Anathondi, Pithondi (Ml) Annaithondi (Tm)	—	—	—	—
76.	*Swintonia floribunda*	Assam, TN and Kerala	Civit	—	—	—	—	—
77.	*Tectona grandis*	TN, MP, Maharashtra, Orissa, WB, Bihar, Gujarat, UP, AP and Karnataka	Teak	Sagon (As) Shegun (B) Sagwan (H) (O) Sagon (MP) Sag (G) (Mr) Tegu (K) Teku (Tl)	U	I	e	M

(*Continued*)

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
78.	*Terminalia bellirica*	UP, MP, Maharashtra, Kerala, Arunachal Pradesh, Bihar and Karnataka	Bahera (H) (Mr)	Bhaira (P) Bhomora (As) Lupung (Kol) Bahada (O) Baheda (G) Thare, Tari (K) Vehela (Mr) Tham (Ml) Tani (Tm) (Tl)	U	III	b	M
79.	*Teminalia bialata*	Andamans	White chuglam (silver gray wood)	Safed chuglam (And)	—	III	e	M
80.	*Terminalia chebula*	Maharashtra, MP, TN, Nagaland, Kerala, Bihar, Karnataka and Arunachal Pradesh	Harda (myrobalan)	Hararh, Harr (H) Harar (P) Allale (K) Pulincakku (Ml) Cola ippakku, Illagukan Kadukkai (Tm) Karakkai (Tl)	V	III	c	H
81.	*Terminalia manii*	Andamans	Black chuglam	Kalachuglam (And)	V	III	a	M
82.	*Teminallia paniculata*	Karnataka, Kerala and TN	Kindal (Mr)	Honal, Hunol (K) Kindal (Mr) Honagalu (K) Pillamarudu (Tm) (Ml) Nallapulaga (Tl)	V	II	c	H
83.	*Terminalia tomentosa* (*T. crenulata, T. Coriacea, T. alata*)	Bihar, UP, Maharashtra, AP, Kerala, Karnataka and Gujarat	Laurel	Asan, Asna, Sain (H) Aisan (P) Latana (Kol) Puccasaj (N) Sahaja (O) Ain, Sadan, Saj (MP) Malli, Karimathi, Banapu (K) Mathi (Tm) Karimarudu (Ml) Nallamaddi (Tl) Sajad, Ain (Mr)	U	II	b	H
84.	*Thespesia populnea*	Maharashtra and Karnataka	Bhendi (Mr)	Hoovarasu (K) Bhendi (Mr)	—	—	—	—
85.	*Xylia xylocarpa*	Maharashtra, TN, AP, Kerala, Gujarat and Karnataka	Irul	Kongra, Thangan (O) Suria (Mr) Sauriya (MP) Tirwa, Jambe (K) Jamba (Mr) Irul (Tm) Kondatangedri (Tl)	V	I	e	H

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
86.	*Zanthoxylum bundranga* (*Fagara bundrunga*)	AP and TN	Mullilam (Tm)	Bujarnali (As) Badrang Timur (B) Morai (O) Jamin (K) Tirphul (Mr) Mullilam (Tm) Rhetsa (Tl)	W	II	—	M
87.	*Zanthoxylum rhetsa* (*Fagara bundrunga*)	AP	Mullilam (Tm)	Bujarnali (As) Badrang Timur (B) Morai (O) Jamin (K) Tirphul (Mr) Mullilam (Tm) Rhetsa (Tl)	W	—	—	—
GROUP C								
88.	*Acacia leucophloea*	—	Hiwar (H)	Hiwar, Nimbar (H) Gohira, Gwaria, Johira (O)	—	—	—	H
89.	*Acer* spp.	HP and J&K	Maple	Kanjula (Garhwali) Kainju Jaunsari Kulu (Kumaon) Kengel Mandar (P) Kapasi (B) Kapashi (N)	—	III	—	M
90.	*Adina cordifolia*	Maharashtra, Karnataka, TN, Assam, Bihar, MP, Nagaland, Kerala and UP	Haldu (H) (Mr)	Taraksopa (As) Ranyaket (B) Karam (H) Kumbha (Kol) Kuruma (O) Karam (MP) Yellaga, Heddi, Yetagal (K) Haldwar (G) Kuranyan, Malaveppur (Ml) Malam Kommai (Tm) Hedu (Mr)	V	III	a	M
91.	*Aegle marmelos*	—	Hel		—	III	—	—
92.	*Afzolia bijuga* (*Intsia bijuga*)	—	—		—	—	—	—
93.	*Albizzia procera*	UP, WB, Assam, MP, Bihar, Gujarat, Kerala, Maharashtra and Arunachal Pradesh	White siris (safed siris)	Safedsiris, (H) Sit (And) Korois (As) (B) Tentura (Kol) Dhalasirish (O) Kinhai (Mr) Gurer (MP) Karangro (G) Ballati kirai, Sabragai (K) Vellavakka (Ml) Vellavagai (Tm) Tellachindugu (Tl)	V	II	e	M

(Continued)

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
94.	*Anthocephalus cadamba* (*Anthocephalus chinensis*)	Assam, WB, Andamans, and Nagaland	Kadam	Sanko (Kol) Kadamba (O) Attutekku kadambam (Ml) Kalaaiyila, Vellakadam (Tm)	V	III	a	L
95.	*Arecanut* (*Areca* sp.)	—	—	—	—	—	—	—
96.	*Artocarpus chaplasha*	Assam, WB, Andamans and Arunachal Pradesh	Chaplash	Tangupeina (And) Cham, Sam (As) Chaplash (B) Latore (N)	V	II	d	M
97.	*Artocarpus integrifolius* (*Artocarpus laterophylus*)	TN, Maharashtra, Kerala, Bihar, AP and Karnataka	Jack kathal (H)	Rukkatar (N) Kunthal (H) Panas (O) (Mr) (G) Pila (Tm) Panasa (Tl) Halsin, Alasna (K)	V	I	—	M
98.	*Artrocarpus lakoocha*	UP and Karnataka	Lakooch (And)	Das (Kol) Dahua (B) Vata (K)	—	—	—	—
99.	*Azadirachta indica* (*Melia indica*)	UP, MP, Arunachal Pradesh, Gujarat and Karnataka	Neem	—	—	—	—	—
100.	*Bassia latifolia* (*Madhuka latifolia*) *Madhuka indica, M. langifolia*	MP, Maharashtra, TN, UP, Gujarat, WB and Karnataka	Mahua (Mr)	Mohwa (H) (M.P.) Madkam (Kol) Mahula (O) Mahuda (G) Mohwa (Mr) Nathuillupai (Tm) Ippi, Sonnaippi (K) Ippa (Tl)	V	I	e	H
101.	*Betula alnoides* (spp.)	—	Birch	Bhojapatra, Bhuj (H) Sheori (HP) Burza (Kesh) Sarr (N) Diengling (Kasi)	—	—	—	M

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
102.	*Bischofia javanica*	Assam, WB, TN and Maharashtra	Bishop wood upiam	Yepadauk (And) Kanjel (B) (N) Bok (Mr) Nalimara (K) Cholavenga (Ml) Cholavengai, Malachadayan (Tm)	—	III	e	H
103.	*Boswellia serrata*		Salai (H) (Mr)	Shala (P) Salga (H) Salia (MP) Saledi (G)	V, R	III	e	L
104.	*Bridelia retusa* and spp.	Bihar, Orissa, UP, WB, Karnataka and Maharashtra	Kasi	Gondini, Khaja, Khajo (Him) Ghaj (H.P) Kulir (As) Kaka (Kol) Goya (N) Kosi (O) Guji, Komangi (K) Mulluvenga (Ml) Mulvengai (Tm) Karramanu (Tl)	V	II	e	M
105.	*Bursera serrata* (*Protium serratum*)	Orissa and AP	Murtenga	Gutgotia (B) Kaka, Kander (Kol) Nimburamoi (O)	W	II	e	M
106.	*Callophyllum wigtianum* and sp.	TN, WB, Karnataka and Maharashtra	Poon	Goja, Salhoma (K) Punna (Ml) Katupinnai (Tm) Surhonni (K)	W	II	e	M
107.	*Careya arboria*	Maharashtra, TN, UP, MP, Kerala, Naga~~land and Aru-~~nachal Pradesh	Kumbi	Kimbbi (As) (B) (Mr) Kambi (H) Kaval (K) Kumbia (Mr)	V	I	—	H
108.	*Castonopsis hystrix* and sp.	WB, Assam, Nagaland, and Arunachal Pradesh	Indian chestnut	Hingori (As)	W	II	b	M
109.	*Cedrela toona* (*Toona ciliata*)	UP, WB, Assam, Kerala, Bihar, Gujarat, Nagaland and Karnataka	Toon	Tun (H) Jatipoma (As) Katangai (Kol) Tuni (N) Mahalimbo (O) Gandhagarige (K) Chuvannagil (Ml) Malavemba (Tm) Galimanu (Tl) Hiligandhagiri (K) Devdari (Mr)	V	III	c	M

(*Continued*)

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
110.	*Cedrus deodara*	Punjab, UP and Tehri Garhwal	Deodar (H)	Kelo, Kelon (H.P) Diar (P)	V	I	c	L
111.	*Chlorophora excelsa*	—	—	—	—	—	—	—
112.	*Cocunut*		—	—	—	—	—	—
113.	*Cupressus torulosa*	UP and Punjab	Cypress	Devidayar, Leuri (H) Saro (HP) Surai (Kumaon)	W	I	e	L
114.	*Dalberia sissoo*	Punjab, UP, WB, Assam, Bihar and Bihar and Coorg.	Sissoo	Tahli (P) Shishum (H)	V	II	e	M
115.	*Dillenia indica* and spp.	WB, Assam, Nagaland, Kerala, Karnataka and Arunachal Pradesh	Dillenia	Zinbyun (And) Otenga (As) Chatta Tartari (B) Punchpal (N) Rai (O) Kanagole (K) Karmal (Mr)	V	III	—	M
116.	*Dillenia pentagyna*	—	Dillenta	Zinbyun (And) Otenga (As) Chatter Tertari (B) Panchpal (N) Rai (O) Kanagole (K) Karmal (Mr)	V	—	—	—
117.	*Dispyros melanoxylon* and sp.	MP	Ebony	Kendu, Abnos (H) Kend (B) Tiril (Kol) Tendu, Tumri (MP) Tamronj, Timberovo, Timmu (G) Balai (K) Temburni (Mr)	—	III	—	M
118.	*Duabanga sonneratioides (grandiflora)*	WB, Assam and Andamans	Lampati	Myauk—Myo (And) Khodam (As)	—	III	c	L

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
119.	*Elacacarpus tuberculatus* and other sp.	TN and Karnataka	Rudrakshi (rudrak)	Bhutslikadambola (K) Ammakoram, Kodavasi (Ml) Ruchaksham (Tm)	W	—	—	L
120.	*Engelhardtia spicata*	—	Moglaipoma	—	—	—	—	
121.	*Frenela rhomboides*	—	—	—	—	—	—	—
122.	*Gardenia latifolis* and sp.	—	Gardenia	Papra (H) Damkavudu, Kotaranja (O) Papur (Mr) Papri, Dikamali (Mr) Kambil (Tm)	W	—	—	—
123.	*Gmelina arborea*	WB, Assam, Nagaland, Arunachal Pradesh, AP, Kerala, Bihar, UP and Gujarat	Gamari (H)	Kumulu, Shivana, Kulimara, (K) Kumilu (Ml) Kumil (Tm) Gummidi (Tl) Ghamhar, Khamhar, (H) (P) (B) Yamane (And) Kasmor (Kol) Gomani (As) Swan (MP) Shivani Shiwan (G) (Mr) Khamari (N)	V	I	—	M
124.	*Hardwickia binata*	Maharashtra, MP, TN and Karnataka	Anjan (Mr)	Koracha, Karachi (K) Yepi (Tl) Acha (Ml) (Tm)	V	I	e	H
125.	*Heterophragma roxburghii* (*Heterophragma quadriloculare*)	MP and Maharashtra	—	—	—	—	—	—
126.	*Holoptelia integrifolia*	UP and Karnataka	Kanju (H)	Papri (H) Kumkar, Rajani (P) Anjan (B) Chilbil, Dhanuranjo (O) Papra (Mr) Chilwal, Chirol Karanji (MP) Aval (Ml) Thapsi (K) Ayili (Tm)	V	III	b	M

(*Continued*)

Sl No.	*Botanical Name*	*Locations where Grown*	*Standard Trade Name (IS : 1150)*	*Names in some other Languages*	*Approximate Quantity Available per Year*	*Durability*	*Treatability*	*Refractoriness*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
127.	*Hymenodictyon excelsum*	Assam, Central India, and South India	Kuthan	Bhorkundi (As) Baurang, Bhurkal, (H) Lathikaram (N) Bausa (O) Bathura (P) Bhonsal (Mr) (MP) Bhowarmal, Bhuskar (MP) Bhoga (Mr) Bogi, Doddothopa (K) Vellakadamba (Ml) Paranjothi, Sagapu (Tm)	—	III	c	L
128.	*Juglans* spp.	HP and J&K	Walnut	Akhor, Akror, Khor (H)	—	III	—	M
129.	*Lagerstroemia flosreginae* (*Lagerstroemia speciosa*) (*Lagerstroemia hypoleuca*)	Assam, WB, TN, Andamans and Arunachal Pradesh	Jarul (pyinma) (in Andmns)	Ajhar (As) Garasekre (Kol) Panipatuti (O) Holadasal (K) Bandara taman (Mr) Nimmaruthu (Ml) Poomaruthu, Pumarudu (Tm) Pyinma (And)	W	II	e	M
130.	*Lannea coromandelica* (*Odina wodiere*)	All over India	Jhingan (H)	Jhingan, Moyen (H) Kembal (P) Nabe (And) Ruhimala, Kuhimala (As) Jial, Jiga (B) Dokan (Kol) Jeol (N) Moi (O) Moyal (MP) Modhal Monia (G) Gojjal, Geru (K) Moyen Model, Moyee (Mr) Annallara, Uthi (Ml) Kalesan, Odiyamaram (Tm) Cumpini (Tl)	—	III	e	M

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
131.	*Lannea grandis* (*Odina wodiere*)	—	Jhingan	Jhingan, Moyen (H) Kembal (P) Nabe (And) Ruhimala, Kubimala (As) Jial, Jiga (B) Dokan (Kol) Jeol (N) Moi (O) Moyal (MP) Modhal Monia (G) Gojjal, Geru (K) Moyen Model, Moyee (Mr) Geru (K) Moyen Uthi (Ml) Kalesan, Odiyamaram (Tm) Gumpini (Tl)	—	—	—	—
132.	*Laphopetalum wightianum*	Karnataka, TN and Maharashtra	Banati	Balpala, Binete (K) Karuka, Venkatevu (Ml) Vengothai (Tm)	V'R	III	—	L
133.	*Machilus macrantha* and other sp.	WB and Arunachal Pradesh	Machilus	Gulmar, Gulum, Gulmas, Gulmavo (K) Paswa (Mr)	—	I	—	L
134.	*Mallotus philippinensis*	-	Raini	—	—	—	—	—
135.	*Magnifera indica*	Throughout India	Aam (mango)	Am (H) (As) Amb (P) Uli (Kol) Amba (O) (Mr) Mavu (K) Mamaram (Tm) Mamidi (Tl)	U	III	a	L
136.	*Manglietia isignis*			—	—	—	—	—
137.	*Melia Indica* (*azadarach*)	UP	Dersian lilac neem poplar bakain (H)	Bakain, Daree (H)	—	III	—	M
138.	*Michelia champaca*	WB and Assam	Champ	Titasopa (As) Champak, Chempaca (B) Champa (H) (O) Sampige (K) Chambegam (Tm) Champakam (Tl)	—	III	—	M
139.	*Michelia champaca* and sp	WB and Assam	Champa	Sopa (As) Champa (B) (O)		-	—	—
140.	*Michelia excelsa*	WB and Assam	Champ	Sopa (As) Chempa (B) (O)	—			—

(Continued)

Sl No.	Botanical Name	Locations where Grown	Standard Trade Name (IS : 1150)	Names in some other Languages	Approximate Quantity Available per Year	Durability	Treatability	Refractoriness
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
141.	*Michelia montana*	WB and Assam	Champ	Sopa (As) Chempa (B) (O)	—	—	—	—
142.	*Miliusa velutina*	UP	Domsal		—	—	—	—
143.	*Mitragyna parvifolia* (*Stephegyna parviflora*)	MP, UP, Orissa, TN, Maharashtra and Karnataka	Kaim	Kalam, Phaldu (H) Kalam, Guri (H) Hamsabeti (Kol) Mitukuniya (O) Kalam (MP) (G) Kadever (K) Kadam, Kalmb (Mr)	U	III	b	M
144.	*Morus alba* and sp. other than laevigata	Punjab, WB, Assam and UP	Mulberry	Shahatut (H) (P) Tut (P)	—	III	—	M
145.	*Morus laevigata*	Assam	Bola	Bhola (As) Kimbu (B) (O)	—	—	—	—
146.	*Morus serrata*	Assam	Tooli	Shehatoot (H) (P) Tut (P)	—	—	—	—
147.	*Ougenia dalbergiodes* (*Ougenia oojeinensis*)	MP, Maharashtra, AP, UP, Gujarat and Karnataka	Sandan (H)	Pandhan, Bandhan, Panan, Tinnas, Tinsa (H) Sannam (P) Ruta (Kol) Tinse, Tiwas (MP)	V	I	—	M
148.	*Porrotia jacquemontiana* (*Parrotiopsis jacquemontiana*)	—	Parrotia pohu	Kilar, Pasir, Po, Pohu (P)	—	—	—	M
149.	*Phoebe goalparansis* and spp.	Assam, Nagaland, WB and Arunachal Pradesh	Bonsum	Angari (N)	W	III	c	M
150.	*Phoebe hainesiana* and other spp.	Assam, Nagaland, WB and Arunachal Pradesh	Bonsum	Angari (N)	W			

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
151.	*Pinus insularis* (*Pinus khesiya*)	—	Khasi pine	Diengse, Diengsa (As) Saval (B) Vehal (Manipur)	—	III	—	L
152.	*Pinus longifolia* (*Pinus roxburghii*)	UP, Punjab, J&K and Nagaland	Chir (H)	Chil (P)	—	III	b	L
153.	*Pinus wallichiana* (*Pinus excelsa*)	Punjab and UP	Kail (H)	Kail (H)	V	III	c	L
154.	*Pistacia integerrima*	—	—	—	—	—	—	—
155.	*Podocarpus nerrifolia* and spp.	Andamans	Thitmin	—	—	II	—	—
156.	*Polyalthia cerasoides* and spp.	—	Debdaru (nedunar)	Kutheria (O) Gauri Murgausi (K) Nareila (Ml) Nedunaria (Tm)	—	III	—	M
157.	*Polyathia fragrans* and spp.	TN and Maharashtra	Nedunar		-	-	-	—
158.	*Pterospurmum acerifolium*	UP, WB, Nagaland, Arunachal Pradesh and Karnataka	Hattipalla	—	W	III	c	M
159.	*Shima wallichii*	Assam	Chilauni	Gogra, Makrisal (As)		III	d	M
160.	*Shorea assamica*	Assam, WB	Makai	Makai (As)	—	III	e	M
161.	*Sonneratia apetala*		Keora	Keowra (B)	-	-		M

(*Continued*)

Sl No.	Botanical Name	Locations where Grown	Standard Trade Name (IS : 1150)	Names in some other Languages	Approximate Quantity Available per Year	Durability	Treatability	Refractoriness
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
162.	*Stereospermum chelonoides* (*Stereospermum personatum* and sp.)	WB, Assam, Nagaland, Kerala, Karnataka and Arunachal Pradesh	Padri	Padel, Parel (H) Paroli (As) Husi (Kol) Parari (N) Patuli (O) Padar (MP) Kandol (G) Genersing, Mukanti (K) Kursing Pindoli (Mr) Kaladri, Pathiri (K) Padiri (Ml) (Tm) Isikirasi (Tl)	V	III	—	M
163.	*Stereospermum suaveolens*	WB, Assam, Nagaland, Kerala, Karnataka and Arunachal Pradesh	Padri	Padel, Parel (H) Paroli (As) Husi (Kol) Parari (N) Patuli (O) Padar (MP) Kandol (G) Genesing Mukanti (K) Kursing, Pindoli (Mr) Kaladri, Pathiri (K) Padiri (Ml) (Tm) Isikirasi (Tl)	V	—	—	—
164.	*Stereospermum xylocarpus*	—	Vedonkonnai	Padel, Parel (H) Paroli (As) Husi (Kol) Parari (N) Patuli (O) Padar (Ml) Kandol (G) Genesing Mukanti (K) Kursing, Pindoli (Mr) Kaladri, Pathiri (K) Padiri (Ml) (Tm) Isikriasi (Tl)	—	—	—	—
165.	*Tamarindus indica*	—	Imli (H) (Mr)	Jogo (Kol) Tenthuli (O) Hunse (K) Puli (Tm) Chintamanu (Tl)	—	I	—	M
166.	*Terminalia arjuna*	MP, WB, Maharashtra, TN, Gujarat and Karnataka	Arjun	Kowa (Kol) Arjuna (O) Koha (Mr) Kohu, Kowa (MP) Billimaddi Thoramathi (K) Vellilava (Ml) Vellamaruthu (Tm) Tellamaddi (Tl)	U	II	b	M
167.	*Terminalia myriocarpa*	Assam, WB, Nagaland and Arunachal Pradesh	Hollock	Panisaj (N)	V	III	a	M

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
168.	*Terminalia procera*	Andamans	White bombway (badam)	Badam (And)	—	III	b	M
169.	*Vateria indica*	TN, Karnataka and Maharashtra	Vellapine	Gugle, Maddidhupa, Paini, Dhup, Kaidhupa (K) Payan, Vellakunthinikam (Ml) Vellaikundrikam, Vellapayini (Tm)	—	III	e	L

Abbreviation used *Language*

(And) = Andamanese
(Tl) = Telugu

(As) = Assamese
(H) = Hindi
(G) = Gujarathi
(Hm) = Himachali
(Ksh) = Kashmiri
(Ml) = Malayalam
(K) = Kanarese
(Mr) = Marathi
(H) = Hindi
(N) = Nepalese
(O) = Oriya
(P) = Punjabi
(Tm) = Tamil
(H) = Hindi
(B) = Bengali

Approx Availability

U = More than 2500 tonnes per annum (3500 m^3)

V = Between 1000 and 2500 tonnes per annum (that is between 1400 and 3500 m^3)

W = Less than 1000 tonnes per annum, that is, less than 1400 m

R = The species is heavily demanded by other industries also.

NOTE 1 — Where the trade name is the popular Hindi name, or derived from a local name the abbreviation of the corresponding language is indicated in brackets along with the trade name.

NOTE 2 — '—' indicates that information was not readily available but will be included later when available.

NOTE 3 — For the legend under durability, treatability and refractoriness *see* **2.3.8**; **2.3.9** and **2.3.10** (H = high, M = moderate, L = low)

APPENDIX H

(*Clauses* 2.3.3, 2.3.6.3, 2.3.7, 5.2, 5.3 *and* 5.2.6.3)

MECHANICAL PROPERTIES OF VARIOUS STRUCTURAL SPECIES

(Safe working stresses, Standard Grade (Grade I)—Inside location)

Sl No.	*Species*	*Group*	*Locality from where tested*	*Standard specific gravity*	*Modulus of Elasticity* $\frac{1000\ \text{kg}}{\text{cm}^2}$	*Bending and tension along grain extreme fibre stress* kg/cm²	*Shear*, kg/cm² *Horizontal*	*Shear*, kg/cm² *Along Grain*	*Compression parallel to grain* kg/cm²	*Compression perpendicular to grain*, kg/cm²	*Weight per* m³ *at 12 percent moisture content* (kg)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1.	*Acacia arabica*	B	UP	0.670	97.7	155	14.4	20.6	89	52	797
2.	*Acacia catechu*	A	UP	0.875	134.4	201	15.5	22.1	138	77	1009
3.	*Acacia chundra*	A	MP	0.976	167.9	265	22.4	32.0	179	109	1086
4.	*Acacia forruginea*	B	Maharashtra	0.876	122.8	230	16.5	23.5	139	99	993
5.	*Acacia loucophloca*	C	MP	0.660	78.5	134	10.3	14.7	75	45	737
6.	*Acwe* sp.	C	UP	0.499	77.2	107	9.9	14.7	60	23	615
7.	*Acer* sp.	C	Punjab	—	73.7	99	8.8	12.5	55	21	551
8.	*Acrocarpus fraxinifolins*	B	South India	0.587	125.9	161	12.3	17.6	105	46	690
9.	*Adina cordifolia*	C	UP	0.598	85.4	133	9.6	13.6	87	44	663
10	*Adina cordifolia*	C	South India	—	89.3	131	9.0	12.9	80	32	687
11.	*Adina cordifolia*	B	Bihar	—	99.3	147	9.6	13.7	88	34	681
12.	*Aegle marmelos*	C	UP	0.754	88.1	135	14.0	20.0	88	68	890
13.	*Afzelia bujuga*	C	Andamans	0.606	91.6	132	10.8	15.4	79	40	705
14.	*Aglaia edulis*	A	Assam	0.702	125.6	182	14.1	20.2	101	44	815
15.	*Albizzia lebbeck*	B	S. Andaman	0.549	111.7	134	10.8	15.4	90	44	642
16.	*Albizzia orderatissima*	A	S. India	0.632	135.4	187	15.3	21.9	133	73	737
17.	*Albizzia procera*	C	UP	0.579	90.2	134	9.8	14.0	85	43	643
18.	*Altingia excelsa*	B	Assam	0.667	113.7	171	11.7	18.1	110	68	795
19.	*Amoora rohituka*	B	Assam	0.576	103.6	147	10.3	14.8	89	50	703

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
20	*Anogeissus acuminate*	B	Orissa	0.712	116.7	176	12.7	18.0	108	51	844
21	*Anogeissus latifolia*	B	UP	0.793	105.5	161	11.1	15.9	91	47	892
22	*Anogeissus latifolia*	B	S India	—	122.1	179	12.1	17.2	101	63	967
23	*Anogeissus pendula*	B	UP	0.776	97.5	170	12.8	18.4	98	65	929
24	*Anthocephalus cadamba*	C	Burma	–	82	97	7.0	10.0	59	20	485
25	*Arecanut*	C	Kerala	–	94.8	152	12.2	15.9	108	73	833
26	*Artocarpus chaplasha*	C	Assam	0.447	91.1	132	86	12.2	85	36	515
27	*Artocarpus hirsuta*	B	S India	0.516	104.5	150	7.4	10.5	104	33	600
28	*Artocarpus integrifolia*	C	S India	0.505	94.6	139	10.4	14.8	93	45	617
29	*Artocarpus lakoocha*	C	UP	0.530	61.4	100	9.8	14.1	53	28	647
30	*Atlantia monophylla*	B	Orissa	0.786	103.1	167	14.7	21.0	113	63	897
31	*Azdarichta indica*	C		—	—	—	—	—	—	—	—
32	*Balanocarpus utilis*	A	S India	0.844	169.1	251	15.1	21.6	164	93	987
33	*Bassia butyracea*	B	S Andaman	0.632	106.4	153	10.3	14.8	99	66	780
34	*Bassia latifolia*	C	MP	0.737	88.2	130	10.1	14.4	75	63	936
35	*Betula alnoides*	C	WB	0.553	92.3	96	7.6	10.8	57	22	625
36	*Bischofia javanica*	C	S India	0.551	88.4	98	7.9	11.2	59	36	769
37	*Boswellia serrata*	C	Bihar	0.498	72.1	94	7.3	10.5	55	21	551
38	*Bridelia retusa*	C	Bihar	0.499	94.2	116	8.8	12.6	71	40	584
39	*Bruguiera* sp	A	Andamans	0.797	176.8	219	11.8	16.9	143	55	897
40	*Buchlandia polulnea*	B	WB	0.552	98.9	128	10.5	14.9	79	35	672
41	*Buchlandia polulnea*	B	NFFA	—	103.8	123	9.1	13.0	78	30	641
42	*Busseia serrata*	C	–	—		—	—	—	—		—
43	*Calophyllum* ***tomentosum***	C	Assam	0.532	96.3	128	9.6	13.8	84	36	626
44	*Calophyllum tomentosum*	B	S India	0.531	102.2	133	9.1	13.0	90	28	610
45	*Calophyllum tomentosum*	B	Maharashtra	—	97.7	134	7.9	11.2	86	28	657
46	*Calophyllum wightianum*	C	Maharashtra	0.569	86.8	135	9.5	13.6	87	40	689
47	*Canarium strictum*	B	S India	0.532	118.6	133	8.6	12.3	81	28	655
48	*Carallia lucida*	B	Assam	0.624	126.0	184	12.2	17.4	114	59	748
49	*Carapa moluccusis*	B	Burma	–	104.0	156	9	12	100	46	786
50	*Careya arborea*	C	UP	0.644	83.7	131	10.3	14.8	77	53	889
51	*Cassia fistula*	B	UP	0.746	118.0	192	14.3	20.4	123	72	865
52	*Cassia siamea*	B	MP	0.697	105.0	154	9.8	13.9	108	55	820
53	*Castanopsis hystrix*	C	WB	0.515	98.5	106	8.2	11.7	64	27	624
54	*Casuarina equisetifolia*	B	Orissa	0.693	114.4	146	12.7	18.1	82	40	769
55	*Cedrela toona*	C	UP	0.424	64.0	87	7.0	10.0	54	24	487

(*Continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
56.	*Cedrus deodara*	C	HP	0.468	94.8	102	7.0	10.0	78	27	557
57.	*Chlorophora excelsa*	C	S. India	0.402	65.7	102	4.9	7.0	64	20	471
58.	*Chlroxylon swietenia*	B	MP	0.834	116.9	182	13.7	19.6	109	63	865
59.	*Chloroxylon swietenia*	B	S. India	—	115.4	173	13.6	19.5	120	72	960
60.	*Chukrasia tabularis*	B	WB	0.568	83.5	118	10.5	15.0	71	39	666
61.	*Coconut*	C	Kerala	0.558	65.1	83	4.5	6.4	70	37	625
62.	*Cullenia excelsa*	B	S. India	0.532	124.3	147	6.4	9.1	90	27	625
63.	*Cullenia rosayroana*	B	—	—	—	—	—	—	—	—	—
64.	*Cupressus torlosa*	C	UP	0.437	84.1	88	5.7	8.2	69	24	506
65.	*Cynometra polyandra*	A	Assam	—	132.0	191	12.8	18.4	117	57	903
66.	*Delbergia sissoo*	C	UP	0.667	88.9	144	10.8	15.5	88	39	808
67.	*Delbergia sissoo*	C	Bihar	—	84.2	157	12.7	18.1	96	55	774
68.	*Delbergia sissoo*	C	Punjab	—	71.4	128	12.5	17.9	82	42	799
69.	*Delbergia sissoo*	C	WB	—	95.9	155	11.0	15.7	97	44	748
70.	*Dichopsis elliptica*	B	S. India	0.533	118.6	139	7.2	10.3	85	29	606
71.	*Dichopsis polyantha*	B	Assam	0.594	112.4	149	11.1	15.9	99	47	734
72.	*Dillenia indica*	C	WP	—	86.1	121	8.3	11.8	73	27	647
73.	*Dillenia pentagyna*	C	WB	0.531	75.6	118	9.4	13.4	71	36	622
74.	*Diospyros. melanoxylon*	C	Maharashtra	0.678	76.9	109	8.5	12.2	70	33	818
75.	*Diospyros microphylla*	B	Maharashtra	0.626	121.5	142	9.1	12.9	83	33	776
76.	*Diospyros pyrrhocarpa*	B	N. Andaman	0.703	99.3	135	9.8	14.0	79	40	843
77.	*Dipterocarpus bourdilloni*	B	Kerala	0.577	127.1	136	7.1	10.2	78	25	699
78.	*Dipterocarpus grandiflorus*	B	N. Andaman	0.606	117.1	125	7.7	11.0	79	27	758
79.	*Dipterocarpus indicus*	B	Karnataka	0.618	162.9	158	8.9	12.7	103	31	757
80.	*Dipterocarpus macrocarpus*	A	Assam	0.595	133.4	145	7.5	10.6	88	35	726
81.	*Duabanga sonneratioides*	C	WB	0.429	83.8	98	6.0	8.5	64	18	485
82.	*Dysoxylum malabaricum*	B	S. India	0.581	109.2	132	9.9	14.1	80	31	745
83.	*Elaeocarpus tuberculatus*	C	S. India	0.403	87.3	97	7.0	9.9	63	20	466
84.	*Engelhardtia spicata*	C	Assam	0.660	62.0	84	7.0	10.1	48	25	580
85.	*Eucalyptus eugenioides*	B	S. India	0.671	114.7	164	12.2	17.4	113	76	853
86.	*Eucalyptus globulus*	A	S. India	-	148.3	159	10.3	14.8	90	34	912
87.	*Eucalyptus* sp.	A	UP	0.785	164.9	238	14.8	20.6	159	93	917
88.	*Eugenia gardneri*	B	S. India	0.758	119.4	148	11.4	16.2	92	59	952
89.	*Eugenia jambolana*	B	UP	0.647	109.4	16	12.1	17.3	97	47	773
90.	*Eugunia* sp.	B	Assam	0.678	105.5	148	11.1	15.8	90	69	841

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
91	*Fraxinus excelsior*	B	Punjab	0.600	104.1	148	11.7	16.7	81	33	719
92	*Fraxinus micrantha*	B	U.P.	0.605	106.9	150	12.2	17.4	85	43	712
93	*Frenela rhomboidea*	C	S. India	0.516	64.8	92	7.0	10.0	69	40	607
94	*Gardenia latifolia*	C	M.P.	0.635	71.3	141	12.9	17.0	84	46	705
95	*Garuga pinnata*	B	U.P.	0.511	75.8	117	10.1	14.5	72	34	571
96	*Gluta travancorica*	B	S. India	0.621	127.3	135	9.1	13.0	90	40	726
97	*Gmelina arboria*	C	U.P.	0.445	70.2	98	8.4	12.1	57	42	501
98	*Grewia tiliaefolia*	A	S. India	0.665	148.2	183	13.1	18.7	120	60	788
99	*Grewia vestita*	B	W.B.	0.606	120.0	154	13.7	19.5	91	41	758
100	*Hardwickia binata*	C	M.P.	0.733	66.4	141	12.9	18.4	90	74	852
101	*Hardwickia pinnata*	B	S. India	0.528	106.2	132	8.8	12.6	82	29	617
102	*Heritiera sp*	B	Assam	0.694	133.7	179	12.7	18.1	110	65	872
103	*Heterophragma roxburghii*	C	M.P.	0.525	86.9	123	6.7	9.6	79	34	616
104	*Holoptelea integrifolia*	C	U.P.	0.498	74.6	120	8.9	12.8	67	28	592
105	*Hopea glabra*	A	S. India	0.869	147.9	213	15.3	21.9	145	99	1081
106	*Hopea parviflora*	A	S. India	0.794	130.3	186	12.9	18.4	132	92	923
107	*Hymenodictyon excelsum*	C	U.P.	0.418	64.3	79	7.0	9.9	47	19	494
108	*Juglans fallax*	B	Kashmir (low)	0.490	101.9	130	8.4	12.1	75	27	573
109	*Juglans fallax*	C	Kashmir (high)	0.482	93.0	114	7.9	11.2	66	24	544
110	*Juglans sp*	C	H.P.	0.529	93.5	114	9.3	13.3	65	22	614
111	*Juglans sp*	C	Punjab		97.2	131	9.6	13.7	77	24	561
112	*Juglans sp*	C	U.P.	0.530	90.0	99	8.5	12.2	58	22	565
113	*Kayea floribunda*	B	Assam	0.665	108.8	168	11.0	15.7	101	44	813
114	*Lagerstroemia flosreginae* *Lagerstroemia hypoleuca* }	C	N. Andaman	0.517	85.3	121	8.2	11.7	77	34	622
115	*Lagerstroemia lanceolato*	B	S. India	0.554	107.6	127	8.4	12.0	82	34	617
116	*Lagerstroemia lanceolato*	B	Maharashtra		113.4	145	9.9	14.1	93	48	732
117	*Lagerstroemia parviflora*	B	U.P.	0.620	109.7	143	10.9	15.5	87	37	734
118	*Lannea coromandelica*	C	Rajasthan	0.497	55.5	92	8.9	12.7	58	36	577
119	*Lannea grandis*	C	U.P.		56.3	85	6.4	9.1	49	22	557
120	*Lophopatalum wightianum*	C	S. India	0.374	73.3	85	5.3	8.3	53	18	460
121	*Machilus macrantha*	C	S. India	0.445	76.3	102	7.1	10.2	63	24	521
122	*Machilus odoratissima*	B	W.B.	0.570	100	124	10.3	14.7	82	35	692
123	*Mallotus philippinensis*	C	U.P.	0.571	75.1	108	9.6	13.6	60	29	662
124	*Mangifera indica*	C	Orissa	0.588	91.2	122	9.6	13.7	73	31	661
125	*Manglietia insignis*	C	Assam	0.409	103.7	109	6.8	9.8	80	34	449

(*Continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
126.	*Melia indica*	C	UP	—	85.2	146	12.9	18.4	100	50	836
127.	*Mesua ferrea*	A	Assam	0.862	163.0	233	12.3	17.6	155	59	965
128.	*Mesua ferrea*	A	S. India	—	172.9	243	16.7	23.9	158	93	1335
129.	*Michelia cathcartii*	C	WB	—	103.6	104	7.8	11.2	62	19	524
130.	*Michelia champaca*	C	WB	0.426	83.9	113	7.5	10.3	71	25	494
131.	*Michelia excelsa*	C	WB	0.441	101.2	108	6.0	8.5	67	22	507
132.	*Michelia excelsa*	C	NEFA	—	101.2	98	7.2	10.3	61	16	513
133.	*Michelia montana*	C	WB	0.437	82.5	109	7.2	10.2	66	28	512
134.	*Milliusa belutina*	C	UP	0.625	79.2	117	11.4	16.3	70	37	747
135.	*Mismsops elingi*	B	S. India	0.740	123.9	173	12.7	18.1	110	56	885
136.	*Mimusops littoralis*	A	S. Andaman	0.902	173.9	227	14.7	21.0	142	113	1103
137.	*Mitragyna parvifolia*	C	UP	0.558	78.2	126	10.4	14.9	79	37	651
138.	*Morus alba*	C	UP	0.603	82.0	118	10.0	14.3	66	38	743
139.	*Morus laevigata*	B	Assam	0.541	121.2	165	11.2	16.0	99	41	651
140.	*Morus laevigata*	C	Andamans	—	86.1	123	10.2	14.6	72	33	588
141.	*Morus serrata*	C	HP	0.577	70.3	102	9.1	13.0	56	26	657
142.	*Ougeinia dalborgioides*	C	MP	0.704	85.4	133	12.1	17.2	85	51	784
143.	*Ougeinia dalbergioides*	C	UP	—	95.5	166	13.8	19.7	92	63	785
144.	*Parrotia jacqucmontiana*	C	HP	0.680	57.7	125	11.5	16.5	68	40	761
145.	*Phoebe goalparensis*	C	Assam	0.422	76.5	97	7.0	10.1	66	22	511
145A.	*Phœbe hainensiana*	C	Assam	0.75	95.0	132	8.4	12.1	88	28	566
146.	*Pinus insularis*	C	NEFA	0.431	73.8	89	5.7	7.4	58	15	513
147.	*Pinus roxburghii*	C	UP	0.448	98.2	85	6.2	8.8	60	20	525
148.	*Pinus wallichiana*	C	Pakistan	—	68.0	66	6.0	8.0	52	17	515
149.	*Pistacia integerrima*	C	J & K	0.433	73.2	131	12.0	17.1	80	43	881
150.	*Planchonia andamanica*	B	S. Andaman	0.693	131.0	161	9.5	13.6	108	49	913
151.	*Podocarpus neriifolia*	C	S. Andaman	0.463	94.1	125	6.1	8.6	80	26	533
152.	*Poeciloneuron indicum*	A	S. India	0.902	162.9	224	16.3	21.8	147	87	1139
153.	*Polyalthia cerasoides*	C	MP	0.586	92.9	132	9.7	13.9	71	32	700
154.	*Polyalthia fragrans*	C	Maharashtra	0.445	91.5	119	8.3	11.9	67	30	752
155.	*Pterocarpus dalbergioides*	B	N. Andaman	0.620	112.4	171	10.2	14.6	120	55	721
156.	*Pterocarpus marsuipium*	B	Maharashtra	0.671	102.5	149	9.4	13.4	91	41	803
157.	*Pterocarpus santalinus*	A	S. India	-	127.3	250	17.4	24.8	181	118	1121
158.	*Pterospermum acerifolium*	C	WB	0.507	95.5	135	8.5	12.2	87	32	607
159.	*Quereus incana*	B	Punjab	0.826	108.2	158	12.2	17.5	87	50	1008
160.	*Quereus lamellosa*	B	WB	0.609	124.4	145	11.5	16.5	87	38	870

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
161.	*Quereus licneata*	B	WB	0.681	126.3	152	12.1	17.3	96	53	874
162.	*Quereus semeoarpifolia*	B	Punjab	0.692	115.8	158	12.7	18.1	83	38	834
163.	*Quereus* sp.	B	NEFA	—	116.5	114	10.4	11.9	67	20	657
164.	*Saccopetalum tomentosum*	B	Maharashtra	—	110.6	148	9.3	13.2	97	35	745
165.	*Sageraea elliptica*	A	S. Andaman	—	150.6	215	10.5	15.0	125	53	869
166.	*Schima wallichii*	C	WB	0.539	95.7	111	8.9	12.8	66	23	693
167.	*Schleichera trijuga*	A	Burma	—	130	225	16.0	23.0	152	85	942
168.	*Shorea assamica*	C	Assam	0.479	92.7	111	9.1	12.9	71	29	548
169.	*Shorea robusta*	B	MP	—	126.7	169	9.4	13.4	106	46	805
170.	*Shorea robusta*	A	WB	0.730	150.1	196	10.3	14.6	123	59	895
171.	*Shorea robusta*	A	UP	—	127.9	196	12.6	17.9	120	80	886
172.	*Shorea robusta*	A	Bihar	—	144.3	191	13.9	19.9	123	93	887
173.	*Shorea robusta*	A	Assam	—	133.8	191	14.4	20.6	121	74	837
174.	*Shorea talura*	A	Maharashtra	—	122.0	168	11.0	15.6	126	68	721
175.	*Soneratia apetala*	C	WB	0.521	86.3	128	9.2	13.2	74	48	617
176.	*Soymida febrifuga*	B	S. India	0.965	122.2	215	16.2	23.2	150	129	1116
177.	*Sterculia alata*	B	Assam	—	109.5	134	8.4	12.0	82	27	593
178.	*Stereospermum chelonoides*	C	WB	0.605	92.2	138	11.9	17.0	89	40	717
179.	*Stereospermum chelonoides*	C	S. India	—	129.4	190	11.2	16.0	119	40	731
180.	*Stereospermum suaveolens*	C	UP	0.617	88.6	133	9.0	12.9	78	35	721
181.	*Stereospermum xyocarpum*	C	S. India	—	85.2	132	10.6	15.2	90	43	696
182.	*Swintonia floribanda*	B	Burma	—	115.0	123	9	13.0	70	22	640
183.	*Tamarindus indica*	C	S. India	0.747	56.3	114	12.0	17.1	70	53	913
183A.	***Texus bacata***	C	WB	0.612	77.9	143	12.2	17.4	87	47	705
184.	*Tectona grandis*	B	S. India	0.596	110.2	151	9.4	13.5	96	47	699
185.	*Tectona grandis*	C	MP		84.9	128	8.4	13.0	79	40	617
186.	*Tectona grandis*	C	Orissa		89.3	139	9.8	13.9	86	35	604
187.	*Tectona grandis*	B	WB	—	116.1	162	10.8	15.3	107	36	617
188.	*Tectona grandis*	B	Maharashtra	—	99.7	147	10.4	14.9	90	44	623
189.	*Tectona grandis*	B	UP	—	99.7	155	11.5	16.4	94	45	660
190.	*Terminalia arjuna*	C	Bihar	0.686	77.1	122	11.2	16.0	74	52	794

(*Continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
191.	*Terminalia bellirica*	B	UP	0.628	101.9	136	9.6	13.7	84	37	329
192.	*Terminalia bilata*	B	S. Andaman	0.578	123.8	155	8.7	12.4	98	36	690
193.	*Terminalia chebula*	B	Burma	—	124	171	9	13	70	22	640
194.	*Terminalia manii*	B	S. Andaman	0.665	126.6	168	11.2	16.0	103	51	822
195.	*Terminalia myroecarpa*	C	Assam	0.568	96.2	119	8.5	12.1	76	29	615
196.	*Terminalia paniculata*	B	S. India	0.646	132.2	169	9.1	13.1	109	45	787
197.	*Terminalia paniculata*	B	Maharashtra	—	105.7	131	9.2	13.2	86	36	765
198.	*Terminalia procera*	C	N. Andaman	0.520	89.9	118	8.9	12.7	72	30	626
199.	*Terminalia tomentosa*	B	UP	0.727	116.8	159	9.5	13.6	98	47	842
200.	*Terminalia tomentosa*	B	S India	—	105.4	151	11.0	15.8	94	62	906
201.	*Terminalia tomentosa*	B	Maharashtra	—	130.7	168	10.9	15.6	104	59	795
202.	*Thespesia ponulnea*	B	Maharashtra	0.647	103.6	189	13.2	18.8	113	44	766
203.	*Vateria indica*	C	S. India	0.483	109.5	115	7.3	10.5	75	23	535
204.	*Vitex altissima*	A	Maharashtra	0.771	130.1	182	11.7	16.7	126	95	937
205.	*Xylia xylocarpa*	B	Maharashtra	0.715	116.3	162	12.8	18.3	109	78	839
206.	*Zanthoxylum budranga*	B	WB	0.496	106.5	147	8.7	12.4	95	34	587
207.	*Zanthoxylum rhetsa*	B	Maharashtra	0.609	130.2	155	10.9	15.5	92	39	609

APPENDIX J

(*Clause* 3.1.4)

TYPICAL NUMERICAL EXAMPLE FOR CALCULATING THE COMPARATIVE SUITABILITY INDEX FROM THE BASIC MECHANICAL PROPERTIES

a) Property desired : Strength as a beam

b) Species : *Dalbergia Sissoo* (sissoo or shisham)

(1) Green condition properties grouped:

	Property Value		*Adjusting Factor*		*Weightage Factor*		*Product*
M or R (static bending)	721	×	1	×	2	=	1442.0
FS at EL (static bending)	390	×	1.69	×	1	=	659.1
FS at EL (impact bending)	1104	×	0.69	×	1	=	761.8
					Total		2862.9

$$\text{Group average for green condition (1), } S_A = \frac{\text{Total value}}{\text{Sum of weightage factor}} = \frac{2862.9}{4} = 715.7$$

(2) Dry condition moisture content at 12 percent properties grouped:

	Property Value		*Adjusting Factor X*		*Weightage factor ϕ*		*Product*
M or R (static bending)	1056	×	1.00	×	2	=	2112.0
FS at EL (static bending)	659	×	1.73	×	1	=	1140.1
FS at EL (impact bending)	1087	×	0.83	×	1	=	880.5
					Total		4132.6

Group average for dry condition (2) S_B

$$= \frac{\text{Total value}}{\text{Sum of weightage factor}} = \frac{4132.6}{4} = 1033.1$$

Combining group averages for all conditions and giving a relative weightage of 2 for green condition values as usual:

$$S = \frac{2S_A + S_B}{3}$$

$$= \frac{2 \times 715.7 \times 1033.1}{3} = 822$$

Similarly value for teak, $S' = 878$

Comparative suitability index for the property chosen

$$= \frac{S}{S'} \times 100$$

$$= \frac{822}{878} \times 100 = 95$$

(rounded off to the nearest 5.)

For evaluation of similar properties like suitability as a post, shock resisting ability, nail and screw holding power, refractoriness, hardness, etc (reference may be made to 'Suitability indices of Indian timbers for industrial and engineering uses', by A. C. Sekhar and A. S. Gulati, Indian Forest Records, Vol. 2, No. 1, 1972). Suitability indices for a few selected species and some important properties are given in Table 8.

NOTE — X = Adjusting factors are the average ratios of principal property chosen (that is, the first property mentioned above for grouping) to the auxillary properties chosen (that is, subsequent properties mentioned above for grouping) for each condition, taking data of all species into consideration Hence this is a constant factor and is used to bring the values of concerned properties to the same order and level of considertion before multiplying and adding the same

ϕ = Weightage factors are given to indicate relative importance of the property or condition chosen as compared to other properties and conditions Usually the principal property and green conditions values are given weightage 2 as compared to others for which the weightage is only 1

APPENDIX K

WORKED EXAMPLES

Example 1

Consider a beam of teak of standard grade is required for a span of 5 metres for inside location. Then, from Appendix H,

the permissible stress, $f = 151$ kg/cm^2

Horizontal shear = 9.4

Modulus of elasticity = 110 × 1000 kg/cm^2

Let the beam carry a uniform loading of 100 kg per metre. Since from **5.2.3** and Fig. 6

$$f = \frac{My}{I} = \frac{WL}{8} \cdot \frac{d}{2} \cdot \frac{12}{bd^3}$$

If a beam of 10 cm width (V) is chosen, then from the above equation d will work at 11.2 cm or say 12 cm. It should now be checked for deflection, Δ that it should not be more than $\frac{1}{360}$ of the span, that is, $\frac{500}{360} = 1.4$

The deflection is given by $\Delta = \frac{5}{384} \cdot \frac{WL^3}{E} \cdot \frac{12}{bd^3}$

By substitution of W, L, E, b and d^3, the deflection will work out to 1.04 and this being less than 1.4, the cross-sections chosen are permissible for the span and load.

Since the depth of the beam is less than 30 cm, no form factor is required as in **5.2.4**. For modification factors for duration of loading and slope of grain, reference may be made to Table 17 and 18. For other types of loads, and fixings, appropriate values of M may be taken from Fig. 6.

The shear stress in the above beam is computed by the formula (*see* **5.2.5.1**):

$$H = \frac{3V}{2bd} \quad \text{when } V = \frac{W}{2} = 250$$

Substituting $b = 10$ cm and $d = 12$ cm, we get $H = 3.1$ which is less than permissible shear stress 9.4 for teak as mentioned above. Hence the cross-section is acceptable.

Example 2

If a column of 3 metres of teak of standard grade is required for inside location to carry a load of 6000 kg:

For teak E (from Appendix H) = 110, 200 kg/m^2

and f_{cp} = 96 kg/cm^2

$$\therefore K_8 = 0.702\sqrt{\frac{E}{f_c}} = 23.8 \text{ or say } 24$$

This is more than 11 and hence the formula for intermediate column may be considered with $S = 3$ metres, if we take d as 12.5 cm or more so that $\frac{S}{d}$ does not exceed 23.8 then the permissible stress is only

$$96\left[1 - \frac{1}{3}\left(\frac{300}{24 \times 12.5}\right)^4\right] = 64$$

$$\text{Actually stress} = \frac{6000}{12.5 \times 12.5} = 38.5$$

Since this is less than permissible, it can be used. If we take 10 × 10 cm cross-section then actual stress = 60 and permissible stress

$$96\left[1 - \frac{1}{3}\left(\frac{300}{24 \times 10}\right)^4\right] = 19.2$$

Hence 10 × 10 cm cross-section cannot be used. If the length of the column is 500 cm then a cross-section of 15 × 15 cm would give $\frac{S}{d} = 33.3$ which is more than 24. Hence the formula for long column should be used under which the permissible stress $= 0.329\, E/\left(\frac{S}{d}\right)^2 = 33.4$. But the actual stress $= \frac{6000}{15 \times 15} = 26.6$. Hence this may be allowed. (For considering duration factors *see* Table 17 and for slope of grain in the column *see* Table 18. For end fixings and tapered columns *see* **5.3.3.1**).

Example 3

Suppose a square box column of length 3 metres is required of teak planks of 2.5 cm thickness in inside location to carry a load of 6000 kg.

Then from Table 23 $q = 1.00$; and $U = 0.80$

From Appendix H, $E = 110.2 \times 1000$ kg/cm² and

$f_c = 96$

$$\text{Hence } K_9 = \frac{\pi}{2}\sqrt{\frac{UE}{5qf_c}} = 22$$

If b, the width of the plank is taken as 10 cm, which is not more than 5 times the thickness of 2.5 cm as required, then $d_1 = 12.5$ and $d_2 = 7.5$, and $d_1^2 + d_2^2 = 212.5$

$\therefore \dfrac{S}{\sqrt{d_1^2 + d_2^2}}$ works out as 20.7 which is less than

the above value of K_9. Hence it should be treated as an intermediate column for which permissible stress according to 5.3.4 (b) is:

$$1 \times 96\left[1 - \frac{300^4}{3 \times 22^4 \times (212.5)^3}\right] = 72 \text{ kg/cm}^2$$

But actual load distributed on the cross-section of the box structure of column

$= 6000/(4 \times 10 \times 2.5) = 60$

As this is less than permissible value obtained above the column is acceptable. In fact from the above considerations the column can safely take load up to even 7200 kg.

If on the other hand 8 × 2.5 cm planks are taken for the box column then $\dfrac{S}{\sqrt{d_1^2 + d_2^2}}$ will work out to 25 and so long column formula of 5.3.4(c) should be applied. Accordingly permissible stress f_c will work at only 41.3 kg/cm². This being less than the stress due to actual load, this section is **not acceptable**.

Example 4

Let is be required to analyze stresses in a simple truss as indicated in Fig. 10. The trigonometric method is employed. In Fig. 10 the various joints are represented by J_1, J_2, J_3, etc, and the forces in corresponding members between the joints as Q_1, Q_2, Q_3, etc. From Fig. 10, if L is the span, it is evident that each segment of bottom chord a is equal to $L/6$. Let P be the total worked out load at each joint as indicated. As the extreme angle indicated is 30°, from simple trigonometrical calculations $J_0J_1 = a/\cos 30° = 1.18a$. Similarly it can be shown that

$J_0J_1 = J_2J_3 = J_2J_5 \quad = 1.18\ a$
$J_1J_4 \quad = 0.59\ a$
$J_4J_2 \quad = 1.52\ a$
$J_3J_6 \quad = 1.77\ a$
$J_5J_3 \quad = 2.00\ a$
and $J_0J_4 = J_4J_5 = J_5J_6 \quad = a$

Now for calculation of the forces, let the first joint J_0 be considered

Here $\Sigma V = 3.5P - P + Q_1 \cos 60 = 0$ ...(1)
$\Sigma H = Q_1 \cos 30 + Q_4 = 0$ ...(2)

From Equation (1), $Q_1 = -5P$ and substituting in equation (2),

$$Q_9 = \frac{5P \times 1.7}{2} = 4.3\ P$$

Similarly working at the joint J_1

$\Sigma V = Q_1 \cos 60 - P + Q_4 + Q_2 \cos 60 = 0$

$\Sigma H = Q_1 \cos 30 + Q_2 \cos 30 = 0$

From these equations, $Q_2 = -5P$ and $Q_4 = -P$

Similarly working out at joint J_4

$\Sigma V = -Q_4 + Q_5 \sin 49 = 0$

and $\Sigma H = -Q_9 + Q_5 \cos 49 + Q_{10} = 0$

Substituting known values of Q_4, we get

$Q_5 = 1.32\ P$ (in tension) and $Q_{10} = 3.5P$
(also in tension)

Thus working successively at each joint a table as shown below can be prepared for lengths of each member and forces on the same

Designation of member	*Force*		*Length in Terms of a*
	Q_i	Value in Terms of P	
J_0J_1	Q_1	$-5P$	$1.18a$
J_1J_2	Q_2	$-5P$	$1.18a$
J_2J_3	Q_3	$-4P$	$1.18a$
J_1J_4	Q_4	$-1.0P$	$0.59a$

Designation of member	Force Q_i	Force Value in Terms of P	*Length in Terms of a*
J_2J_4	Q_5	$1.32P$	$1.52a$
J_2J_5	Q_6	$-1.5P$	$1.18a$
J_3J_5	Q_7	$1.73P$	$2.00a$
J_3J_6	Q_8	0	$1.77a$
J_0J_5	Q_9	$4.33P$	a
J_4J_5	Q_{10}	$3.5P$	a
J_5J_6	Q_{11}	$2.63P$	a

The forces and lengths on the right half of the truss will be symmetrical to the left half. By knowing the length of each member and forces acting on the same, taking negative values for compression and positive values for tension, and keeping in view the required uniformity and constructional details, the cross-sections of members can be worked out as columns or beams, etc, as the case may be.

Example 5

Problem To find the number of nails for a nailed joint in a timber frame.

Given

1) Teak species
2) Thickness of member as evaluted by usual design calculation: 3 × 8 cm
3) Lateral strength of 3.5 mm

diameter of 9 S.W.G. in double shear (*see* Table 26) for
Teak timber = 140 kg for
= lengthening joint
= 80 kg for modal joint
= 130 kg for temperate construction

Solution

Total thickness of plates required
= 1.5 × 3 = 4.5 cm

Hence thickness of each plate
= 4.5/2 = 2.25 cm

Length of the nails required
= 3 + (2 × 2.25) = 7.5 cm

For lengthening joints

Let maximum stress be = 750 kg

No. of nails required $= \frac{750}{140}$

= approximately 6 nails on either side of the joint.

These are to be distributed uniformly keeping in view the recommendation on spacing, edge distances and end distances (*see* **6.2.11.2**). The length of the plates works out to be 21 cm.

Nodal joint at right angles

Let the maximum stress be = 450 kg

No. of nails required $= \frac{450}{80}$

= approximately 6 nails

These nails are to be distributed uniformly as per the scheme recommended in **6.2.11.2**.

Example 6

Problem Find the number of nails and the dimensions of the plates in a lengthening joint in a beam.

Given

Species of Group A: Grade I
Service condition: Inside location
Span of the beam: 400 cm
Section of the beam: 15 × 6 cm
Maximum bending moment:
38 310 cm kg
Bending moment (BM) for which joint is designed, say,
= 1/3 of maximum bending moment
= 12 770 cm kg

Solution

Taking lever arm as 2/3 = 2/3 × 15 = 10 cm of indepth of the beam

$$\text{The force in the member} = \frac{\text{BM at the joint}}{\text{lever arm}}$$

$$= \frac{12\,770}{10}$$

$$= 1\,277 \text{ kg}$$

Thickness of plates = 6/2 + 3/2 = 4.5

Total thickness at the joint = (2×4.5)+6 = 15 cm

Lateral strength of nail of 5 mm dia and 150 mm long is assumed to be 200 kg for the given species

No. of nails required on either side of the joint in each of tension and compression zones of the beam

$$= \frac{1277}{200} = \text{Approx. 6 nails}$$

With six nails in each zone on either side of the joint, 24 nails are required. If the distance between the centroids of nail groups on either side is kept at 5 times the lever arm, then it is 5 × 2/3 × 15 = 50 cm. Hence keeping in view the edge distances and end distance, and adjusting the position of nails in between, the length of the plates will work out to be 100 cm. Care should be taken that adjacent nails are driven from opposite faces. The distances between nails are to be checked for conformation to be requirements.

The general design consideration for stresses and deflections of nail jointed beams are the same as of solid beams (IS : 883-1970) and the shear strength for nails for 3.75, 4 and 5 mm diameters and for length of 75, 100, 125 and 150 mm for various species as given in IS : 4983-1968 (*see also* **6.3.2.3**). For some of the light and softer species no pre-boring is recommended but in other cases pre-boring is considered necessary. In such cases the diameter of pre-bore should be lesser than the nominal diameter of the nail by atleast 0.5, 1 and 1.5 mm depending on hardness of the species. But it appears, for convenience of design, the presently recommended forty eight species in IS : 883-1970 can be suitably grouped according to their specific gravity or hardness.

Example 7

Problem To find the number of bolts of 10 mm diameter required for a lengthening joint of a truss member in compression.

Given Species- Teak for which working stress in green condition is 104 kg/cm² and hence for dry condition 15 percent be added = 120 kg/cm²

Thickness of member : 3.5 cm
Force on the member : 1200 kg
Service condition : Inside location

Solution

Length of the bolt in the main member : 35 mm

Diameter of bolt : 10 mm

∴ Bolt L/d ratio : 3.5

Projected area of the bolt : $3.5 \times 1.0 = 3.5$ cm²

Percentage safe working stress (from Table 28) for L/d ratio of 3.5 : 100

∴ Safe working stress of timber for bolted joint $= 120 \times 100$ percent $= 120$ kg/cm²

Safe load per bolt, $f = 120 \times 3.5 = 420$ kg

$$\therefore \text{No. of bolts required} = \frac{\text{Force experienced by member}}{\text{Safe load per bolt}} = \frac{1200}{420}$$

= approximately 3 bolts on either side of the joint.

These bolts are to be distributed symmetrically on either side of the joint

Thickness of the plate = 1/2 the size of main member
= 1/2 × 3.5 = 1.75 cm

Length of the plate $= 2\ (7d + 4d + 7d)$
= 36 cm

Example 8

Problem To calculate the safe load at a node joint at the bottom chord of a roofstruss if bolts of 10 mm are provided.

Given Thickness of middle member at the joint = 3.5 cm. Each side member = 1/2 thickness of main member
Species—Teak, seasoned, Grade I
Service condition: Inside location
No. of bolts: 4

Solution

Safe working stress in compression perpendicular to grain in green condition of teak = 49 kg/cm^2

Adding 15 percent for seasoned condition, f = 57 kg/cm^2
Bolt L/d ratio = 35/10 = 3.5

Percentage of safe stress (from Table 28) for L/d ratio of 3.5, r = 66.2 percent

∴ Modification factor for bolt of 10 mm dia, K = 3.60 (from Table 29)

∴ Safe working stress of timber for bolted joint : $S = f.\ r.\ k$

$$= \frac{57 \times 66.2 \times 3.6}{100}$$

$$= \text{say } 136 \text{ kg/cm}^3$$

Projected area of bolt, $L \times d$ = 3.5 cm^2
Safe load per bolt = 136 × 3.5/476 kg

∴ Safe load for all bolts = 476 × 4
= 1 904 kg

Example 9

If a wooden disc dowel of babul is required and from consideration of members of the joint the diameter of the disc should not exceed 5 cm then the thickness t of the disc is worked out as below:

From Appendix H, for babul, s = 20.6
and c = 89

$$\text{Then } t = \frac{\pi \times 5 \times 20.6}{2 \times 89} = 1.8 \text{ cm or}$$

or to be on the safe side 2 cm such that one cm is embedded in each member.